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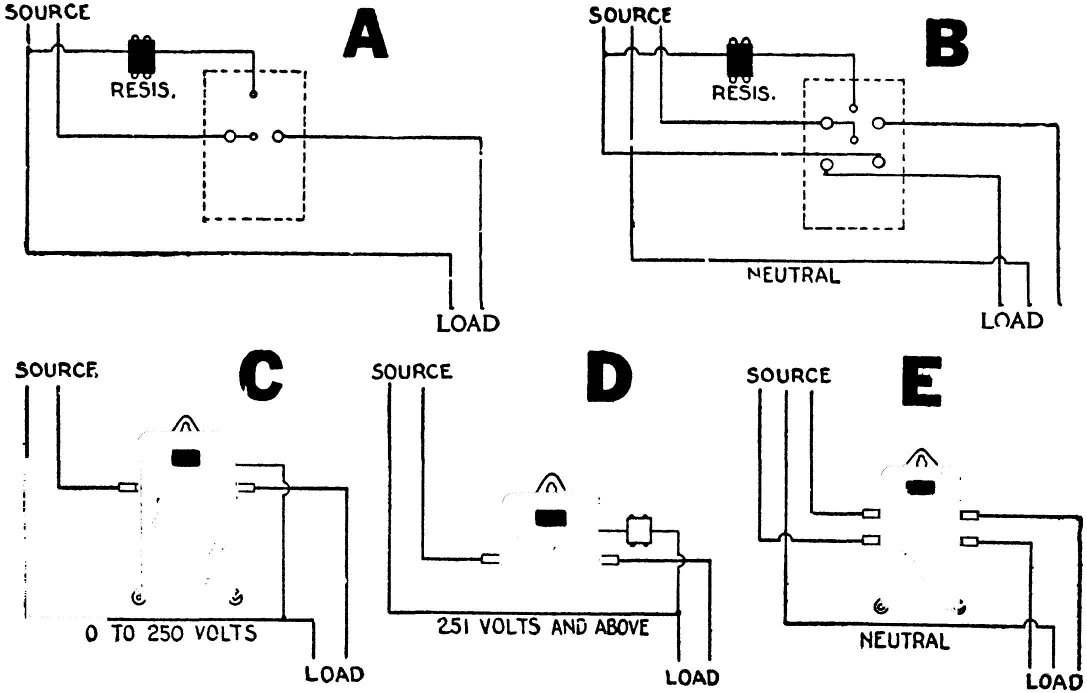

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CHAPTER 37

Galvanometers

If a compass needle be allowed to come to rest in its natural position, and a current of electricity be passed through a wire just over it from north to south, the north seeking end of the needle will be deflected toward the east.

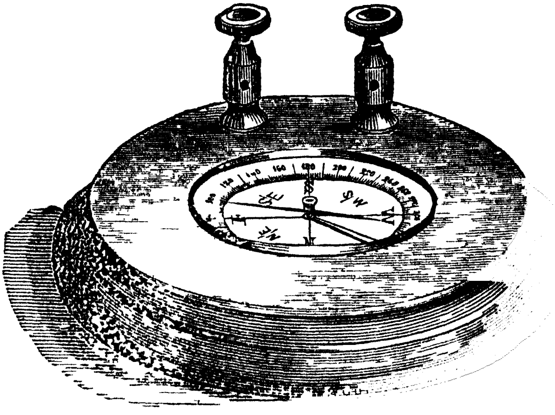


FIG 1,274 —Bunnell simple detector galvanometer It has middle clamps and scale divided into degrees

If the wire be placed under the needle and the current continued from north to south the needle will be deflected toward the west.

Again, if the current be passed from north to south over the needle, and back from south to north under the needle, as shown in fig. 1,276, the magnetic effect will be doubled, and the needle deflected proportionately. Upon these phenomena depend the working of galvanometers.

Ques. Describe a simple galvanometer.

Ans. It consists essentially of a magnetic needle suspended within a coil of wire, and free to swing over the face of a graduated dial.

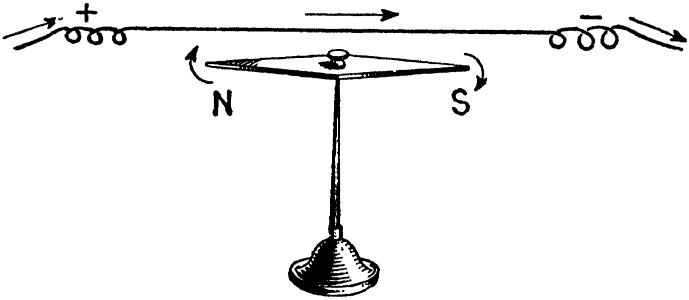


FIG. 1,275.—Effect of a neighboring current upon a magnetic needle. Above the needle and parallel to it is a conductor carrying an electric current, the current flowing in the direction indicated by the arrow. This causes the north pole of the needle to turn toward the east. If the conductor be held *below* the needle, its north pole will turn in the opposite direction or toward the west. These movements are easily determined by Ampere's rule as follows. ***If a man could swim in the conductor with the current, and turn to face the needle, then the north pole of the needle will be deflected toward his left hand.***

Ques. What is a galvanoscope and how does it differ from a galvanometer?

Ans. A galvanoscope, as shown in fig. 1,276, serves merely to indicate the presence of an electric current without measuring its strength. A galvanometer is an indicator of currents, in which the movement of the needle shows the direction of the current, and indicates whether it is a strong or a weak one.

When the value of the readings has been determined by experiment or calculation any galvanoscope becomes a galvanometer.

Ques. For what use are galvanometers employed?

Ans. They are used for detecting the presence of an electric current, and for determining its direction and strength.

Ques. How is the direction and strength of the current indicated?

Ans. When a galvanometer is connected in a circuit, the direction of the current is indicated by the side toward which the north pole of the needle moves, and the current strength by the extent of the needle's deflection.

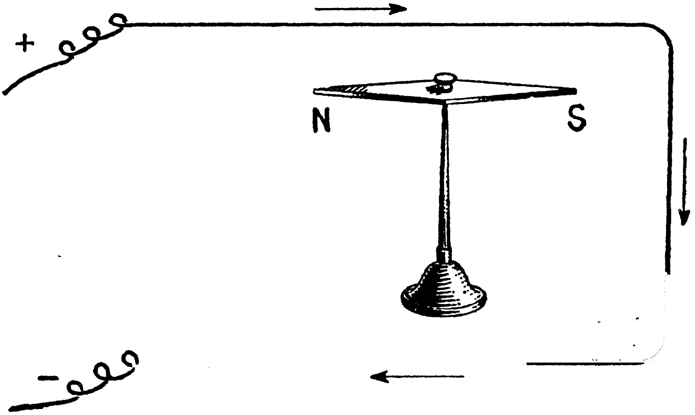


FIG. 1,276.—Effect upon a magnetic needle of a neighboring current in a loop. In this arrangement the same conductor is simply carried back *beneath* the needle and hence both the upper and lower portions tend to turn it in the same direction, while the side branch or vertical section is ineffective. In accordance with Ampere's swimming rule, the *upper* wire causes the N pole of the needle to turn to the left, while if a man imagine himself swimming in the lower wire in the direction of the current, and facing the needle (that is, swimming on his back), the N pole of the needle will turn to his left—that is to the east. The effect of the loop then has double the effect of the single wire in fig. 1,275.

Ques. How should a galvanometer be set up before using?

Ans. When no current is flowing, the coil should be parallel to the magnetic needle when at rest.

Ques. What is a "sensitive" galvanometer?

Ans. One which requires a very small current or pressure to produce a stated deflection.

It does not follow that a galvanometer which is sensitive for current measurement will also be sensitive for pressure measurement.

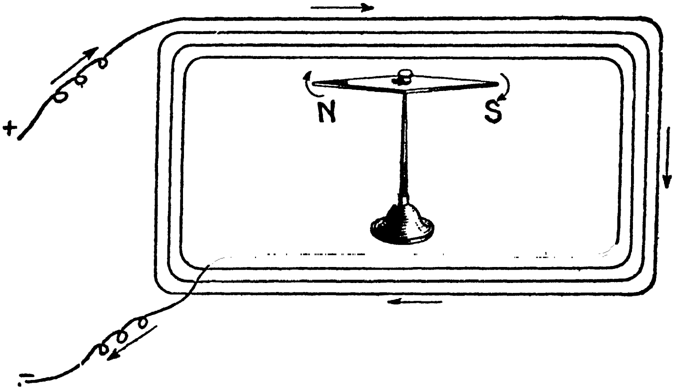


FIG. 1,277.—Effect upon a magnetic needle of a neighboring current in a coil. The coil as shown, is equivalent to several loops, that is, the force tending to deflect the needle is equal to that of a single loop multiplied by the number of turns. Hence, by using a coil with a large number of turns, a galvanometer may be made very sensitive so that the needle will be perceptibly deflected by very feeble currents. An instrument, as shown in the figure is called a *galvanoscope*. When it is accurately constructed, and supplied with a scale showing how many degrees the needle is deflected it is then called a galvanometer.

Ques. Define the term "sensitivity."

Ans. With reference to mirror reflecting galvanometers it may be defined in three ways. First, in *megohms*, the sensitivity being the number of *megohms* through which one volt will produce a deflection of one millimeter with the scale at distance of one meter. Second, in *micro-volts*, the sensitivity being the number of micro-volts which applied directly to the terminals of the galvanometer will produce a deflection of one millimeter with the scale one meter from mirror. The sensitivity is best stated in megohms for high resistance galvanometers and in micro-volts for low resistance galvanometers, and is frequently given both for galvanometers for intermediate resistance. Third, in micro-amperes, the sensitivity being the

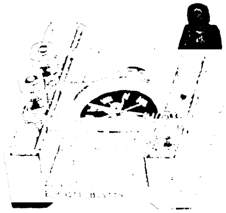
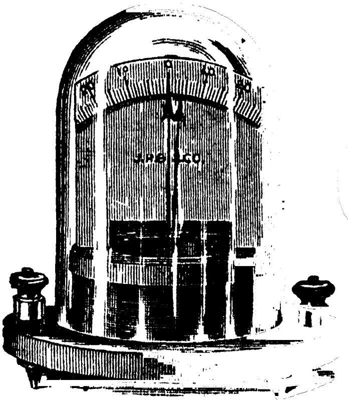


FIG 1,278 —Knott galvanoscope It has three separate circuits, 1, 25 and 100 turns with binding post for each circuit



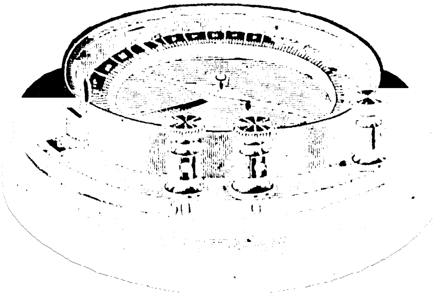


FIG. 1,279 —Breguet upright galvanometer with glass shade

FIG 1,280 —Bunnell horizontal galvanometer It has two coils, one of which is of zero resistance and one of fifty ohms resistance adapting it to a variety of tests number of micro-amperes that will give one millimeter deflection with scale at a distance of one meter.

Ques. Upon what does the sensitivity depend?

Ans. 1, Upon the number of times the current circulates around the coil, 2, the distance of the needle from the coil, 3, the weight of the needle, 4, the current strength, and 5, the amount of friction produced by its movement.

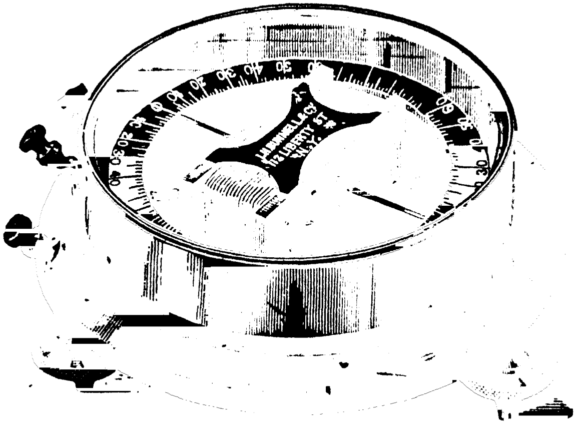


Fig. 1,281.—Bunnell galvanometer for measurement of instruments, lines, batteries, wires etc., from $\frac{1}{100}$ to 10.000 ohms or more.

NOTE.—The definition of ***voltage sensitivity*** given on page 946 is the one recommended by the *U. S. Bureau of Standards*. Some foreign makers, however, specify the sensitivity in terms of the voltage impressed directly across the terminals of the galvanometer without the critical damping resistance in series. The latter sensitivity may be several times the former. This fact should be borne in mind when selecting a galvanometer.

NOTE.—***Strong currents*** must not be passed through very sensitive galvanometers, for even if they be not ruined, the deflections of the needle will be too large to give accurate measurements. In such cases the galvanometer is used with a shunt, or coil of wire arranged so that the greater part of the current will flow through it, and only a small portion through the galvanometer.

The needle is usually quite small, and often a compound one. In very sensitive galvanometers, the coils are wound with thousands of turns of very fine wire, and shunts are generally used in connection with them.

Ques. What two kinds of coil are used?

Ans. The short coil and the long coil.

Ques. What is the difference between a short coil and a long coil galvanometer?

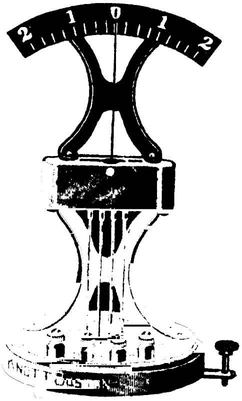


Fig. 1,282.—Knott lecture table galvanometer. Adapted for use in simple lecture table experiments, where high sensibility is not essential. The scale is large and open.

Ans. A short coil galvanometer has a coil consisting of a few turns of heavy wire; a long coil galvanometer is wound with a large number of turns of fine wire.

Ques. What is the action of short and long coil galvanometers?

Ans. With a given current, the total magnetizing force which deflects the needle is the same, but with a short coil, it is produced by a large current circulating around a few turns, instead of a small current circulating around thousands of turns as in the long coil.

The short coil being of low resistance is used to measure the current, and the long coil of high resistance, is suitable for measuring the pressure. Hence, a short coil instrument with its scale directly graduated in amperes is an *ammeter*, and the long coil type with graduation in volts is a *volt meter*.

Classes of Galvanometer.—There are numerous kinds of

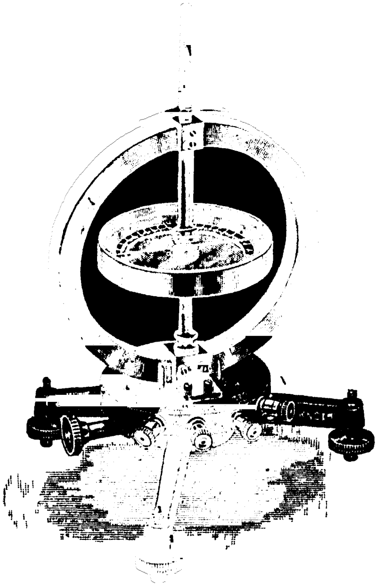


FIG. 1,283.—Knott standard tangent galvanometer with Thompson adjustable control magnet. The suspension system consists of a needle 15 mm long, suspended by fiber and provided with a convenient lift. The needle is protected by a box provided with engine divided dial, the windings are proportioned to meet the conditions of the greatest variety of experiments: 3 turns coarse wire, posts 1 and 2, wound clockwise, 12 turns coarse wire, posts 2 and 3, wound counter-clockwise, giving between posts 1 and 3, nine turns of coarse wire wound counter-clockwise; 320 turns fine wire, posts 3 and 4, wound clockwise, especially designed for determining the constant of a tangent galvanometer.

galvanometer designed to meet the varied requirements. According to construction, galvanometers may be divided into two classes, as those having:

1. Movable magnet and stationary coil;
2. Stationary magnet and movable coil.

Either type may be constructed with short or long coil, and there are several ways in which the deflections are indicated. The principal forms of galvanometer are as follows:

1. Astatic;
2. Tangent;
3. Sine;
4. Differential;
5. Ballistic;
6. D'Arsonval.

Astatic Galvanometer.—It has been pointed out how a compass needle is affected when a wire carrying a current is held over or under it, the needle being turned in one direction in the first instance, and in the opposite direction for the second position of the wire.

The earth's magnetism naturally holds the compass needle north and south. The magnetic field encircling the wire, being at right angles to the needle (when the wire itself is parallel therewith), operates to turn it from its normal position, north and south, so as to set it partially east and west. However, on account of the fact that the earth's magnetism does exert some force tending to hold the needle north and south, it is evident that no matter how strong the current, the latter can never succeed in turning the needle entirely east and west. The accomplishment of this is further prevented by the reason of the points of the needle, where the magnetic effect is greatest, quickly passing out of the reach of the magnetic field, where it is now practically operated on only in a slight degree. Thus it would take quite a powerful current to hold the needle deflected any appreciable distance. The use of a shorter needle is, therefore, more desirable.

It is evident in this style of instrument that the effect of the current cannot be accurately measured, because it acts in opposition to the earth's magnetism, and as this is constantly varying, some method must be employed which will either destroy the earth's magnetism or else neutralize it

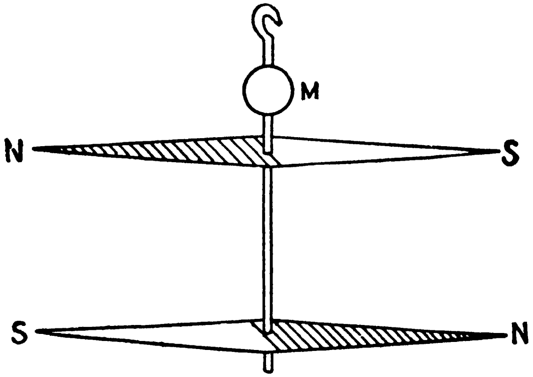


Fig. 1,284.—Astatic needles. Two magnetic needles of equal moment are mounted in opposition on a light support. The whole system is suspended by a delicate fibre, and when placed in a uniform magnetic field such as that of the earth, there will be no tendency to assume any fixed direction, the only restraining influence on the needles being that due to torsion in the suspension fibre.

In the astatic galvanometer, the earth's magnetism is neutralized by means of *astatic needles*. These consist of a combination of two magnetic needles of equal size and strength, connected rigidly together with their poles pointing in opposite and parallel directions, as shown in fig. 1,284.

As the north pole of the earth attracts the south pole of one of the needles, it repels with equal strength the north pole of the other needle, hence, the combination is independent of the earth's magnetism and will remain at rest in any position.

If one of the needles be surrounded by a coil, as shown in fig. 1,285 the magnetic effect of the current will be correctly indicated by the deflection of the needle.

Sometimes each needle is surrounded by a coil, as in fig. 1,286, the coils being so connected that the direction of current in each will tend to deflect the needles in the same direction.

Ques. For what use is the astatic galvanometer adapted?

Ans. For the detection of small currents.

It is used in the "nil" or zero methods, in which the current between the points to which the galvanometer is connected is reduced to zero.

Ques. Upon what does the movement of the needles depend?

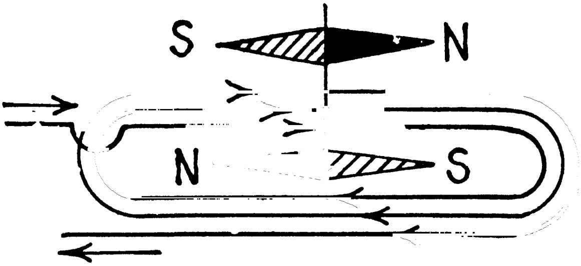


FIG. 1,285.—Connections of single coil astatic needles. The coil surrounds the lower needle and the direction of the current between the two needles tends to turn them the same way.

Ans. Upon the combined effect of the magnetic attraction of the current which tends to deflect the needles, and the torsion in the suspension fibre which tends to keep the needle at the zero position.

Ques. Does the astatic galvanometer give correct readings for different values of the current?

Ans. When the deflections are *small* (that is, less than 10°

or 15°), they are very nearly proportional to the strength of the currents that produce them.

Thus, if a current produce a deflection of 6° it is known to be approximately three times as strong as a current which only turns the needle through 2°. But this approximate proportion ceases to be true if the deflection be more than 15° or 20°.

Ques. Why does the instrument not give accurate readings for large deflections?

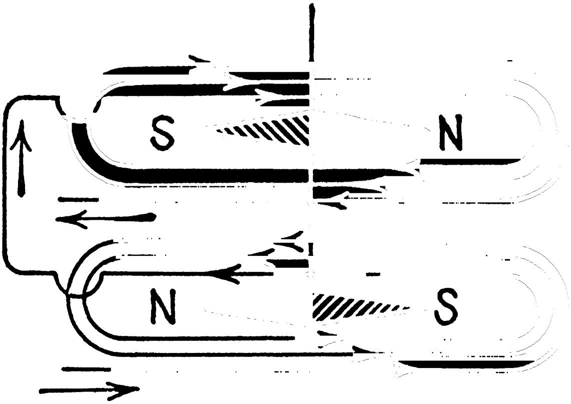


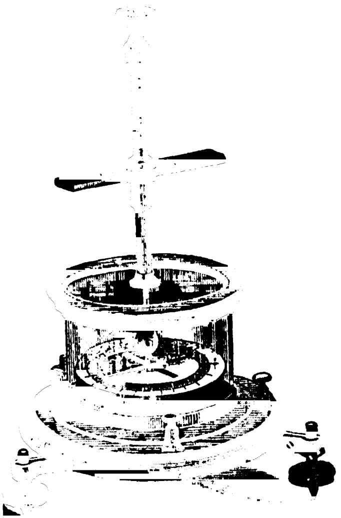
Fig. 1,286.—Connections of double coil astatic needles With this arrangement, the direction of current in both coils will tend to turn the system in the same direction, making the needles more sensitive than with a single coil as in fig. 1,285.

Ans. The needles are not so advantageously acted upon by the current, since the poles are no longer within the coils, but protrude at the side. Moreover, the needles being oblique to the force acting on them, only part of the force is turning them against the directive force of the fibre; the other part is uselessly pulling or pushing them along their length.

Ques. How may correct readings be obtained?

Ans. The instrument may be calibrated, that is, it may be ascertained by special measurements, or by comparison with a standard instrument, what are the amounts of deflection corresponding to particular current strengths?

Thus, if it be once known that a deflection of 32° on a particular galvanometer is produced by a current of $\frac{1}{100}$ of an ampere, then a current of that strength will *always* produce on that instrument the same deflection, unless from any accident the torsion force or the intensity of the magnetic field be altered.



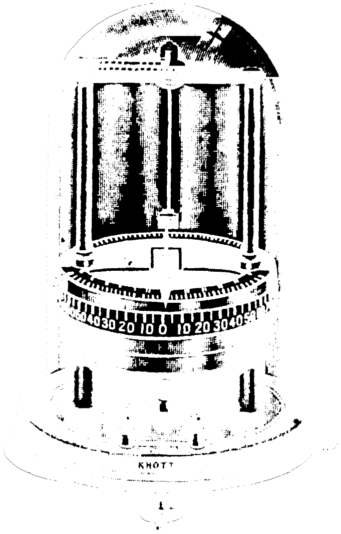


FIG. 1,287 —Queen reflecting astatic galvanometer. It is mounted on a mahogany base with leveling screws A plain mirror is attached above the upper needle. The entire combination of mirror and needles is suspended by unspun silk from the interior of a brass tube, which also carries a weak controlling magnet. A dial 4 inches in diameter and graduated in degrees, enables the deflections of the needle to be accurately read. The mirror can be used with a reading telescope and scale, or by means of a lantern, the image of a slit may be reflected from the mirror to a screen. Resistance, .5 to 1,000 ohms.

FIG. 1,288.—Knott laminated magnet lecture table galvanometer, 30 megohm sensibility.

The Tangent Galvanometer.—It is not possible to construct a galvanometer in which the *angle* (as measured in degrees of arc) through which the needle is deflected is proportional throughout its whole range to the strength of the current. But it is possible to construct a very simple galvanometer in which the *tangent of the angle of deflection* shall be accurately proportional to the strength of the current.

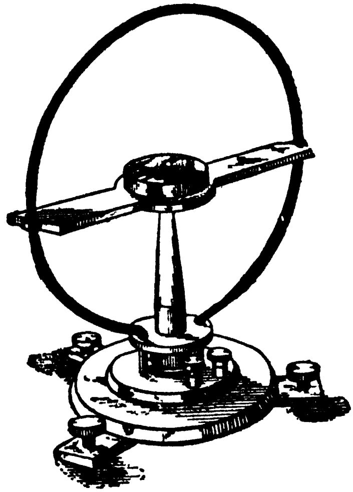


FIG. 1,289.—Tangent galvanometer *It consists of* a short magnetic needle suspended at the center of a coil of large diameter and small cross section. *In practice* the diameter of the coil is about 17 times the length of the needle If the instrument be so placed that, when there is no current in the coil, the suspended magnet lies in the plane of the coil, that is, if the plane of the coil be set in the magnetic meridian, then *the current passing through the coil is proportional to the tangent of the angle by which the magnet is deflected from the plane of the coil*, or zero position—hence the name. "tangent galvanometer."

A simple form of tangent galvanometer is shown in fig. 1,289. The coil of this instrument consists of a single circle of stout copper wire from ten to fifteen inches in diameter. At the center is delicately suspended a magnetized steel needle not exceeding one inch in length, and usually furnished with a light index of aluminum. When the galvanometer is in use, the plane of the ring must be vertical and in the magnetic meridian. A horizontal section through the middle of the instrument is shown in fig. 1,290. For simplicity, the coil is sup-

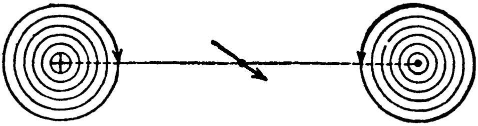


FIG 1,290 —Horizontal section through middle of tangent galvanometer, showing magnetic whirls around the coil and corresponding deflection of needle.

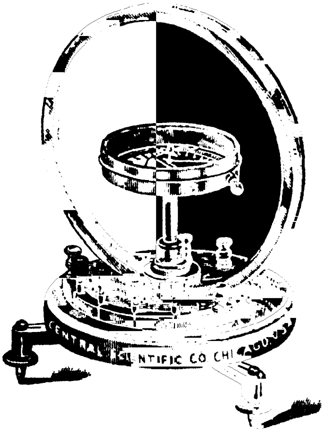


FIG 1,291 —Central Scientific Co tangent galvanometer A 9 inch brass ring is mounted on a mahogany base which rotates on a tripod provided with levelling screws The needle has an aluminum pointer and jewelled bearings The winding consists of 300 turns of magnet wire so connected to the plugs in front that 20, 40, 80, or 160 turns or any combination of these numbers may be used For heavy currents a band of copper is used by connecting to the extra pair of binding posts in the rear of the instrument

posed to have but a single turn of wire, the circles surrounding the wire representing the magnetic lines of force. By extending the lines of force until they reach the needle, it will be seen that with a short needle, the deflecting force acts in an east and west direction when the galvanometer is placed with its coil in the magnetic meridian.

If in fig 1,292, *ab*, represent the deflecting force acting on the N end of the needle, the component of this force that acts at a right angle to the needle will be

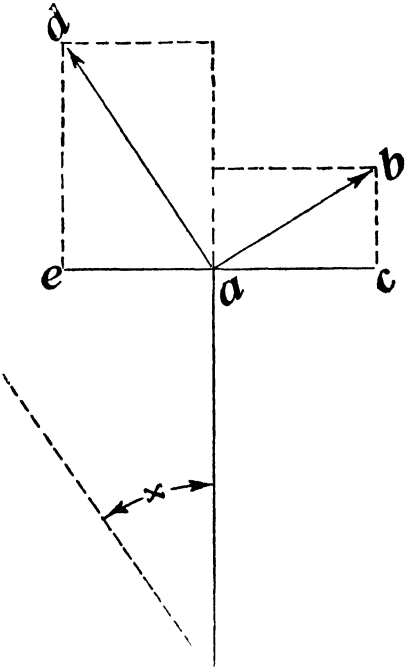


FIG. 1,292 —Diagram of forces acting on the needle of a tangent galvanometer

$$ab \cos x$$

in which, x, is the angle of the deflection.

The controlling force is

$$ad = H$$

and when the needle is in equilibrium, the component, $ae = H \sin x$, is equal and opposite to ac, hence

$$ab \cos x = H \sin x$$

from which

$$ab = H \frac{\sin x}{\cos x} = H \tan x$$

Since *ab*, is proportional to the current,

$$ab = k\,C = H \tan x$$

in which *k*, is a constant depending upon the instrument. For any other current C′,

$$k\,C' = H \tan x'$$

hence

$$C : C' = \tan x : \tan x'$$

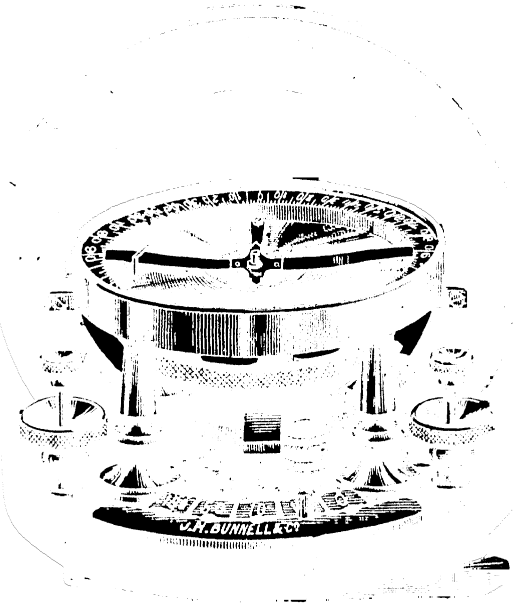


FIG. 1,293.—Bunnell tangent galvanometer. This instrument is mounted on a circular hard rubber base, 7⅜ inches diameter, provided with leveling screws and anchoring points. The galvanometer consists of a magnetized needle ⅞ inch in length, suspended at the center of a rubber ring six inches in diameter, containing the coils There are five coils of 0, 1, 10, 50 and 150 ohms resistance The first is a stout copper band of inappreciable resistance, the others are of different sized copper wires, carefully insulated Five terminals are provided, marked, respectively, 0, 1, 10, 50 and 150 The ends of the coils are so arranged that the plug inserted at the terminal marked 50, puts in circuit all the coils; marked at the terminal 50—all except the 150 ohm coil, and so on, till at the zero terminal only the copper band is in circuit Fixed to the needle, which is balanced on jewel and pivot, is an aluminum pointer at right angles, extending across a five inch dial immediately beneath. One side of the dial is divided into degrees, on the other side, the graduations correspond to the tangent of the angles of deflection.

This means that the currents passing through the coil of a tangent galvanometer are proportional, not to the angle of deflection, but to the tangent of that angle.

Ques. Upon what does the sensitivity of a tangent galvanometer depend?

Ans. It is directly proportional to the number of turns of the coil and inversely proportional to the diameter of the coil.

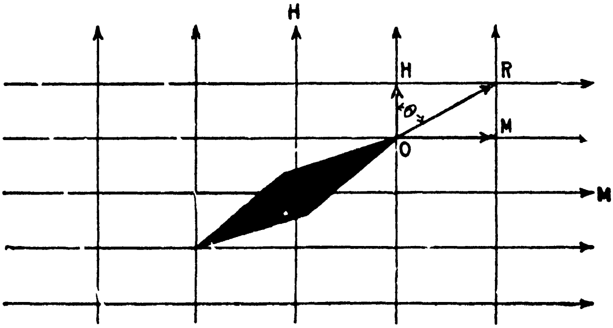


FIG. 1,294 —Diagram illustrating the tangent law This is the law of the combined action of two magnetic fields upon a magnetic needle If two magnetic fields be at right angles in direction as indicated in the figure, the resultant field is obtained by the parallelogram of forces and it makes an angle θ, with one of the component fields such that $\tan O = M + H$, where M, and H, are the strengths of the component fields In the tangent galvanometer this principle is employed in the measurement of currents A magnetic needle is pivoted in a field of known strength The current to be measured is passed round a coil (or coils) which generates a field at right angles to the original field The needle then lies along the direction of the resultant field, and by finding the tangent of its angle of deflection, and knowing the field strength produced by unit current in the coil, the current strength can be found.

Ques. How may the tangent galvanometer be used as an ammeter?

Ans. The strength of the current may be calculated in amperes by the formula given on the next page when the dimensions of the instrument are known.

The needle is supposed to be subject to only the earth's magnetism and to move in a horizontal plane. The current is calculated as follows:

$$\text{amperes} = \frac{H \times r}{N} \tan x \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which

H = constant from table on the next page;
r = radius of coil;
N = number of turns of coil;
x = angle of deflection of needle.

The constant H, given in the following table represents the **horizontal** force of the earth's magnetism for the place where the galvanometer **is** used. Each value has been multiplied by $\frac{2\pi}{10}$ so that the formula (1) for amperes is correct as given.

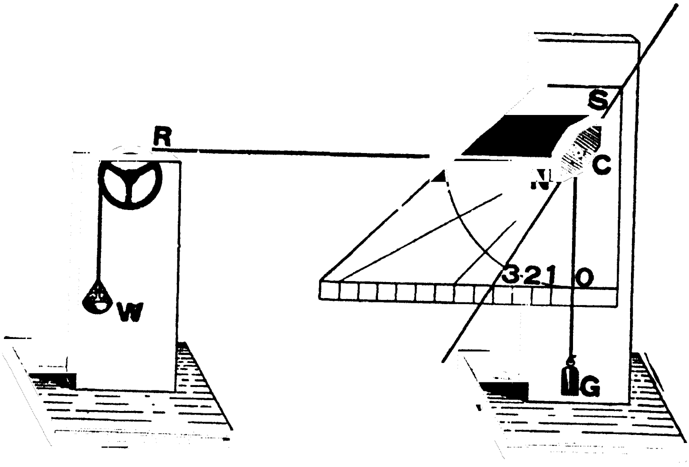


FIG. 1,295.—Mechanical explanation of the tangent law. Construct an apparatus as shown in the figure. The short wooden block, NS, represents the magnetic needle. This piece of wood turns around its center C, which may be an ordinary nail. It will now be seen that two different forces act upon N; namely, the weight G, (one or two ounces), and the changeable weights which are placed in the scoop, W, (made of cardboard). The height of the roll, or wheel, R, is such that the cord, RN, runs horizontally, when NS, stands vertically, *i.e.*, when there is no weight in the little scoop. If the wheel, R, be placed sufficiently far from NS, the string RN will always remain almost horizontal, even if NS, be deviated. The pointer on NS, moves over a horizontal scale, which is divided into equal parts, as shown. This scale may be made of cardboard. If the hand point to division 1, when one ounce is placed in the scoop, it will point to 2, for two ounces, to 3, for three ounces, etc. At 45° the needle is deviated at its greatest angle, and this is, therefore, the sensitivity angle of the tangent galvanometer. The deviating values are, therefore, proportionate to the scale divisions 01, 02, and 03, and so on; and, inasmuch as these themselves are tangents, the tangent law will hold good.

Table of Galvanometer Constants.—Values of **H.**

Boston	.699	New Haven	.731
Chicago	.759	Philadelphia	.783
Denver	.919	Portland, Me.	.674
Jacksonville	1.094	San Francisco	1.021
London	.745	St. Louis	.871
Minneapolis	.681	Washington	.810
New York	.744		

Ques. How is the tangent galvanometer constructed to give direct readings?

Ans. To obviate reference to a table, the circular scale of the instrument is sometimes graduated into tangent values, as in fig. 1,296, instead of being divided into equal degrees.

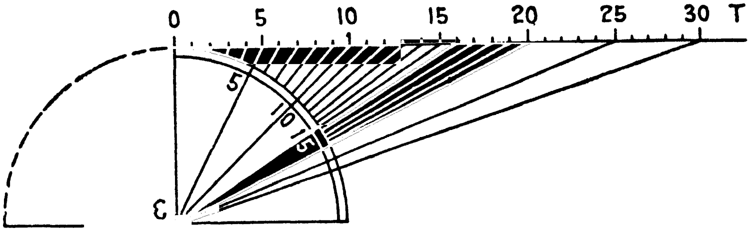


FIG. 1,296.—Graduation of tangent galvanometer scale with divisions representing tangent values. In the figure let a tangent OT, be drawn to the circle, and along this line let any number of equal divisions be set off, beginning at O. From these points draw lines back to the center. The circle will thus be divided into a number of spaces, of which those near O, are nearly equal, but which get smaller and smaller as they recede from O. These unequal spaces correspond to equal increments of the tangent. If the scale were divided thus, the readings would be proportional to the tangents.

Ques. What is the objection to the scale with tangent values?

Ans. It is more difficult to divide an arc into tangent lines with accuracy than into equal degrees.

Ques. What disadvantage has the tangent galvanometer?

Ans. The coil being much larger than the needle, and hence far away from it reduces the sensitiveness of the instrument.

The Sine Galvanometer.—This type of instrument has a vertical coil which may be rotated around a vertical axis, so that it can be made to follow the magnetic needle in its deflections.

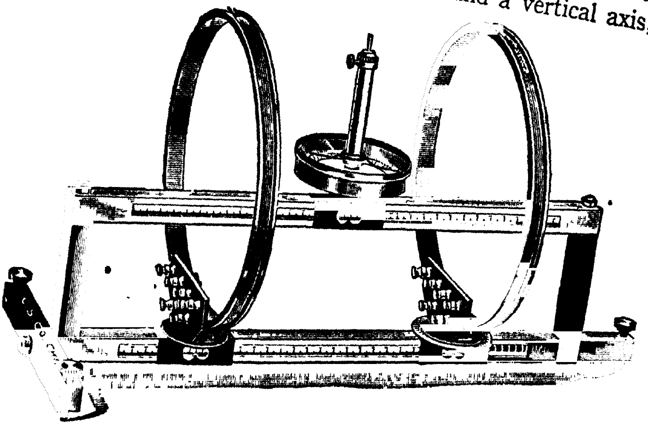


Fig. 1,297.—Central Scientific Co. universal tangent galvanometer. This instrument may be used as a tangent, Gaugain, Helmholtz-Gaugain, sine, cosine, Wiedemann or detector galvanometer. The coils, which slide on a beam parallel to the one carrying the needle box, are wound on brass rings 12 inches in diameter. On each ring are wound two coils of 48 turns each, connected to separate binding posts, and double wound so as to be of equal resistance The coils and needle box are each provided with an indicator for reading their position on the scale. The needle box is swiveled and removable and one coil may be rotated about its vertical axis and its position read on a disc graduated in degrees. Currents may be measured ranging from .000002 ampere to 100 amperes.

In the sine galvanometer, the coil is moved so as to follow the needle until it is parallel with the coil. Under these circumstances, the strength of the deflecting current is proportional to sine of angle of deflection.

Ques. Describe the construction of a sine galvanometer.

Ans. A form of sine galvanometer is shown in fig. 1,298. The vertical wire coil is seen at M. A needle of any length less than the diameter of the coil M, moves over the graduated circle N. The coil M, and graduated circle N, may be rotated on a vertical axis, and the amount of angular movement necessary to bring the needle to zero, measured on the graduated circle H.

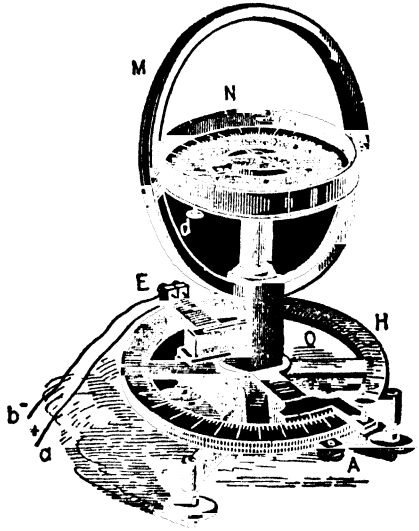


Fig. 1,208.—Sine galvanometer *It differs* from the tangent galvanometer in that the vertical coil and magnetic needle are mounted upon a standard free to revolve around a vertical axis, with provision for determining the angular position of the coil The needle may be of any length shorter than the diameter of the coil. In the figure the parts are M, coil; N, graduated dial of magnetic needle, H, graduated dial by which the amount of rotation necessary to bring the needle to zero is measured, E, terminals of the coil, O, upright standard carrying coil and graduated dial of magnetic needle, C, base with leveling screws

Ques. How is the current strength measured?

Ans. It is proportional to the *sine* of the angle measured on the horizontal circle H, through which it is necessary to turn the coil M, from the plane of the earth's magnetic meridian to the plane of the needle when it is not further deflected by the current.

Ques. How is the sine galvanometer operated?

Ans. In using the instrument, after the needle has been set to zero, the current is sent through the coil, producing a deflection of the needle. The coil is then rotated to follow the motion of the needle, the current being kept constant, the rotation being continued until the zero on the upper dial again registers with the needle. The current then is proportional to the sine of the angle through which the coil has been turned, as determined by the lower dial.

TABLE OF NATURAL SINES AND TANGENTS

∠	Sin.	Tan.	∠	Sin.	Tan.	∠	Sin.	Tan.	∠	Sin.	Tan.	∠	Sin.	Tan.
0°	.0000	.0000	18°	.3090	.3249	36°	.5878	7265	54°	.8090	1.3764	72°	9511	3.0777
			19	.3256	.3443				55	.8192	1.4281	73	9563	3.2709
1	.0175	.0175				37	.6018	.7536	56	.8290	1.4826			
2	.0349	.0349	20	.3420	.3640	38	.6157	.7813				74	9613	3.4874
3	.0523	.0524				39	.6293	.8098	57	.8387	1.5399	75	9659	3.7321
			21	.3584	.3839				58	.8480	1.6003	76	9703	4.0108
4	.0698	.0699	22	.3746	.4040	40	.6428	.8391	59	.8572	1.6643			
5	.0871	.0875	23	.3907	.4245							77	9744	4.3315
6	.1045	.1051				41	.6561	.8693	60	.8660	1.7321	78	.9781	4.7046
			24	.4067	.4452	42	.6691	.9004				79	9816	5.1446
7	.1219	.1228	25	.4226	.4663	43	.6820	9325	61	.8746	1.8040			
8	.1392	.1405	26	.4384	.4877				62	.8829	1.8807	80	.9848	5.6713
9	.1564	.1564				44	.6947	.9657	63	.8910	1.9626			
			27	.4540	.5095	45	.7071	1.0000				81	9877	6.3138
10	.1736	.1763	28	.4695	.5317	46	7193	1.0355	64	.8988	2.0503	82	.9903	7.1154
			29	.4848	.5543				65	.9063	2.1445	83	9925	8.1443
11	.1908	.1944				47	.7314	1.0724	66	.9135	2.2460			
12	.2079	.2126	30	.5000	.5774	48	.7431	1.1106				84	.9945	9.5144
13	.2250	.2309				49	.7547	1.1504	67	.9205	2.3559	85	.9962	11.43
			31	.5150	.6009				68	.9272	2.4751	86	.9976	14.30
14	.2419	.2493	32	.5299	.6249	50	.7660	1.1918	69	.9339	2 6051			
15	.2588	.2679	33	.5446	.6494							87	.9986	19.08
16	.2756	.2867				51	7771	1.2349	70	.9397	2.7475	88	.9994	28.64
			34	.5592	.6745	52	.7880	1.2799				89	9998	57.29
17	.2924	.3057	35	.5736	.7002	53	.7986	1.3270	71	.9455	2.9042			

Ques. Has the sine galvanometer a large range?

Ans. For a given controlling field, it does not admit of a very large range of current measurement, since, for large deflection, on rotating the coil the position of instability is soon reached.

Ques. What is the position of instability?

Ans. The position of the needle beyond which the rotation of the coil will cause it to turn all the way round.

Ques. How may the range be increased?

Ans. By an adjustable controlling field or a shunt.

Ques. What advantage has the sine galvanometer over the tangent instrument?

Ans. Its advantage is in the case where the relative values of two or more currents are required to be measured, or where the constant of the instrument is obtained by comparison with a standard measuring instrument and not calculated from the dimensions of the coil, because all galvanometers thus used follow the sine law independently of the shape of the coil, while only circular coils will follow the sine law.

Damping Effect.—The term "damping effect" means the *offering of a retarding force to control swinging vibrations, such as the movements of a galvanometer needle, and to bring them quickly to rest.*

Frequently the sensitivity is the only characteristic specified, but this is only one of three major characteristics. The critical damping resistance is an extremely important characteristic, as it is very difficult to work with a galvanometer that is improperly damped. If excessively under damped, the galvanometer system oscillates around its position of rest after a deflection, and if excessively over damped it will travel to its position of rest so slowly that it is very difficult to tell when the system has come to rest. A critically damped galvanometer is dead beat; that is, on deflection the system moves to, but does not pass, its new position and comes to rest there in the minimum time, after which, with the removal of the current, the system returns to, but does not pass, its zero position.

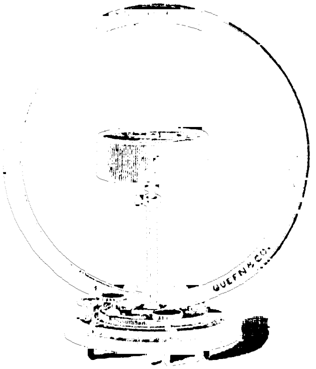


FIG 1,299 —Queen tangent and sine galvanometer. This instrument properly adjusted can be used as a standard instrument for laboratory work. The brass ring is 12 inches in diameter, and the grooves in which the wire is wound are carefully turned so as to be of true rectangular cross section, thus allowing the constant of the instrument to be accurately calculated and compared with the constant as obtained by other methods The compass box is 5 inches in diameter and is so held in position that it may be raised or lowered, rotated on its vertical axis, shifted out of the plane of the coil, etc , thus enabling the operator to acquire proficiency with the instrument and to meet all cases of derangement possible. The dial is graduated to single degrees, and the needle is suspended by a very light cocoon fibre. The whole instrument can be turned about its vertical axis, and a quadrant graduated in degrees upon the base allows the amount of rotation to be accurately measured, and the laws of the sine galvanometer investigated. The instrument is wound to measure .25 ampere to 8 amperes.

Experience has shown that it is most convenient to work with a galvanometer which is just slightly under damped, and it usually pays to sacrifice sensitivity to attain such a condition.

Very often proper damping may be produced by a shunt or a combination of a shunt and series resistance. In specifying a galvanometer, the external critical damping resistance should be stated. If this cannot be done readily, a complete description of the circuit, external to the galvanometer, should be given

External Critical Damping Resistance.—By definition, this is *the external resistance in the galvanometer circuit necessary to produce the critically damped condition.*

The advantage of the critically damped condition rests chiefly

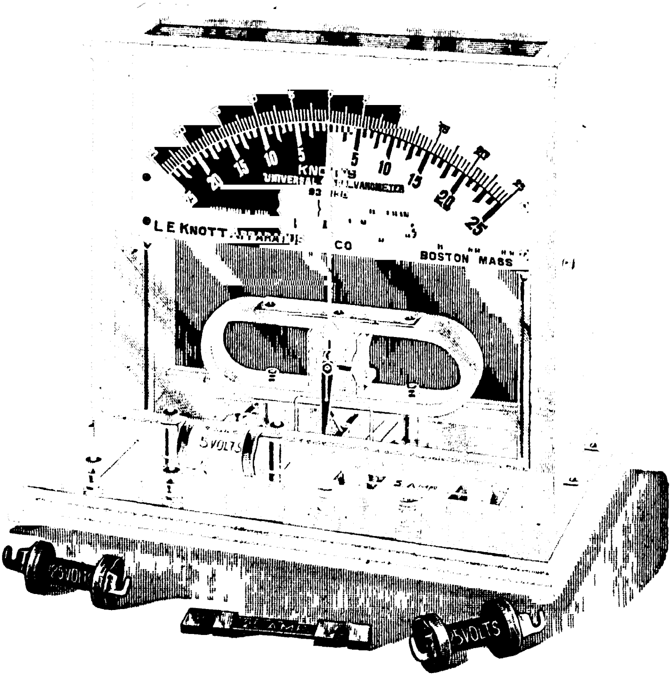


FIG 1,300.—Knott universal lecture table galvanometer *It comprises* eight instruments in one 1, *galvanometer*, one space deflection means 002 amperes or 002 volt, 2, *milli volt meter*, range 25 milli volts reading to ½ milli volt, 3, *milliampere meter*, range 25 milliamperes reading to ½ milliampere, 4, *volt meter*, range 0 to 5 volts reading to $\frac{1}{10}$ volt, 5, *volt meter*, range 0 to 25 volts reading to ½ volt, 6, *volt meter*, range 0 to 125 volts reading to 2½ volts, 7, *ammeter*, range 0 to 5 amperes reading to $\frac{1}{10}$ ampere, 8, *ammeter*. range 0 to 25 amperes reading to ½ ampere in the fact that it aids in rapid work, since a galvanometer system when critically damped returns more promptly to rest than when in an underdamped or over damped condition. Another advantage is that when approximately critically damped the system is prevented passing much beyond its position of rest upon its return, and therefore the zero or nil position is rendered more stable. This conduces to more accurate work when deflections are to be estimated. Practically,

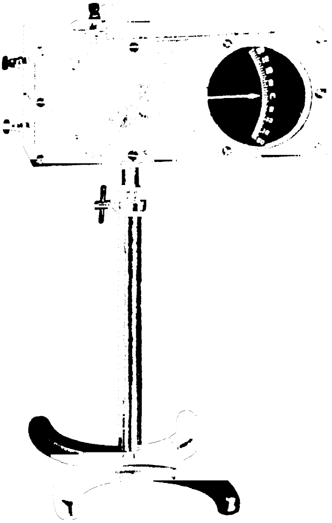


FIG 1,301 —Knott Lampra projection galvanometer, adapted for projection work The scale chamber is of the regulation slide holder size with glass both sides of the indicator. It is arranged to give adequate adjustment for any form of projection lantern, the indicator moving over an arbitrary scale

NOTE —***Period requirements.*** When the proper sensitivity and external critical damping resistance have been decided upon, it usually devolves upon the designer of the galvanometer to secure as short a period as is possible, since the shorter the period the quicker may successive adjustments or readings be made The principal exception to this statement arises in the application of galvanometers to ballistic measurements Here a short period is undesirable In special cases where the period must not exceed a certain value, it is better to specify the period and the external critical damping resistance, leaving it to the designer to obtain the greatest sensitivity possible it is best to work with a galvanometer just slightly underdamped.

The Differential Galvanometer.—This is a form of galvanometer in which *a magnetic needle is suspended between two coils of equal resistance so wound as to tend to deflect the needle in opposite directions.*

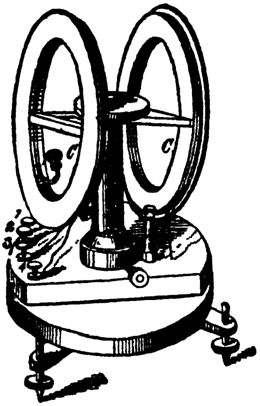


FIG. 1,202.—Differential galvanometer. *It consists* of two coils of wire, so wound as to have opposite magnetic effects on a magnetic needle suspended centrally between them. The needle of a differential galvanometer shows no deflection when two equal currents are sent through the coils in opposite directions, since, under these conditions, each coil neutralizes the effect of the other. Sometimes the current is so sent through the two coils, that each coil deflects the needle in the same direction. In this case the instrument is no longer differential in action. If, when this condition obtains, the magnetic needle be suspended at the exact center of the line which joins the centers of the coils, the advantage is gained by obtaining a field of more nearly uniform intensity around the needle When the needle is suspended by a silk fibre, a final and most delicate adjustment can be obtained by raising or lowering one of the leveling screws slightly, so as to tilt the needle nearer to or farther from one of the coils.

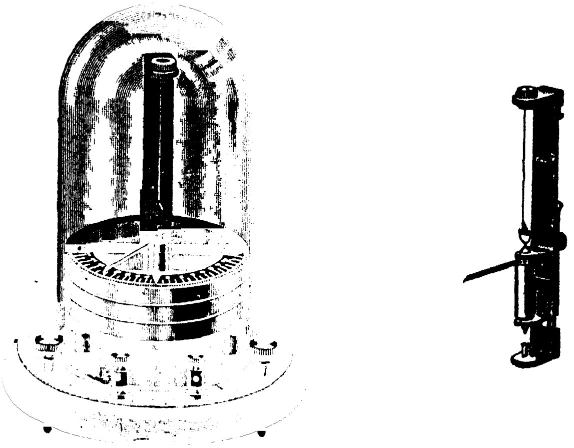
The needle of a differential galvanometer shows no deflection when two equal currents are sent through the coils in opposite directions, since under these conditions, each coil neutralizes the other's effects. Such instruments may be used in comparing resistances, although the *Wheatstone bridge*, in most cases, affords a preferable method.

Ques. Name the special use of the differential galvanometer.

Ans. It is used for comparing two currents.

Ques. What is the method of comparing currents?

Ans. If two equal currents be sent in opposite directions through the coils of the galvanometer, the needle will not move; if the currents be unequal, the needle will be deflected by the stronger of them with an intensity corresponding to the difference of the strength of the two currents.



Figs. 1,303 and 1,304.—Knott triple laminated high school galvanometer, 30 megohm sensibility. The laminated magnets give greater magnetic strength, enabling heavier ribbon suspensions to be used, thus decreasing the liability of breakage. The coil is of the close wound type, and forms part of the suspension system, which can be removed by loosening one screw. The zero adjustment and coil lift operate by turning a knurled screw head. Deflection readings are made directly by pointer moving over a 3½ in. horizontal dial graduated in degrees. This galvanometer is specially adapted for the use of ***ballistic coils*** in capacity and self-induction experiments.

Ques. How are the coils adjusted?

Ans. This is done by coupling them in series in such a way that they tend to turn the needle in opposite directions, and when a current is passing through them they are moved nearer to the needle or farther from it until the needle stands at zero with any current.

If the coils be not movable, a turn or more can be unwound from the coil giving the greatest magnetic effect until a balance is obtained, the wire so unwound can then be coiled in the base of the instrument.

Ballistic Galvanometer.—This type of galvanometer is designed to measure the strength of momentary currents, such for instance, as the discharge of a condenser. In construction the magnetic system is given considerable weight, and arranged to give the least possible *damping effect.*

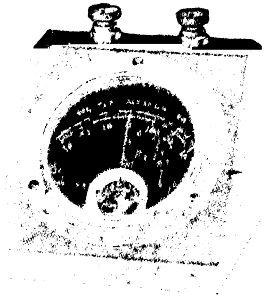


FIG. 1,305.—Weston portable student galvanometer. Resistance approximately 25 ohms The current required for a millimeter (one scale division) deflection is 22 micro-amperes. With 1 volt, a deflection of 1 millimeter will be obtained through 45,500 ohms, but as a deflection of 2 of a millimeter can be readily detected, the galvanometer is, in reality, serviceable through 227,500 ohms This galvanometer is designed for the use of students in colleges and schools, for making bridge measurements, and for the detection of small currents.

If a momentary current be passed through a ballistic galvanometer, the impulse given to the needle does not cause appreciable movement to the magnetic system until the current ceases, owing to the inertia of the heavy moving parts, the result being a slow swing of the needle.

Ques. What name is given to the swing of a ballistic galvanometer needle?

Ans. It is called the *kick*.

Ques. How is the current measured?

Ans. As the needle swings slowly around it adds up, as it were, the varying impulses received during the passage of the momentary current, and *the quantity of electricity that has passed is proportional to the sine of half the angle of the first swing or kick.*

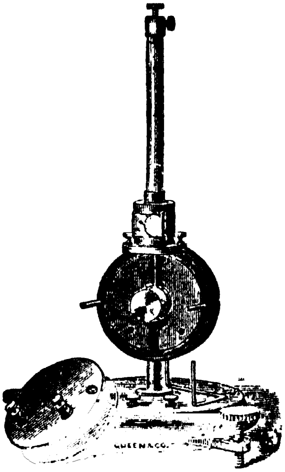
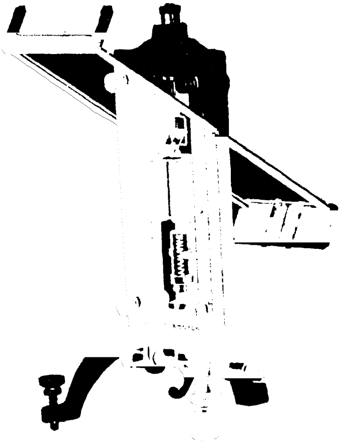


FIG. 1,306.—Queen dead beat and ballistic reflecting galvanometer. ***As illustrated,*** the coils are easily removable and enclose a heavy block of copper fixed in a central fork. In a cylindrical hole bored in this block hangs the bell magnet which with its mirror is suspended by a long cocoon fibre, and the eddy currents induced in the copper bring the system quickly to rest after a deflection. By lifting the copper block out of the frame the instrument is made ballistic. The instrument is made with coils of any desired resistance up to 1,000 ohms.

If a reflecting method be used with a straight scale, the observed deflection depends upon the tangent of twice the angle of movement of the needle. For small deflections, however, the change of flux can be taken as directly proportional to the observed deflection.

Shunted Ballistic Galvanometer.—It may be shown, that in discharging a condenser, for example, through a shunted ballistic galvanometer, *the quantity of electricity divides inversely in* *proportion to the resistance of the two paths*, one through the galvanometer and the other through the shunt. However, the



FIGS. 1,307 and 1,308 —Knott laminated vertical magnet galvanometer, 70 megohm sensibility. The unit suspension system shown in fig 1,308, carries the coil, upper and lower suspension, zero adjustment and coil lift, all comprising a single unit attached to the back base plate. A back target fiducial mark is used, with a front opening wide enough for both edges to be used in their normal position without errors of parallax By removing the reading device, reflections can be read by telescope reading Sensibility is 70 megohm, equal to all requirements for laboratory use, resistance about one ohm per megohm.

NOTE —***A short period*** is undesirable in a galvanometer which is to be used for ballistic measurements Not only does a short period make it difficult to read the maximum deflection or throw, but the throw itself may be appreciably in error if the time of discharge through the galvanometer be not short in comparison with the period of the galvanometer For these reasons a galvanometer for ballistic measurements should have a long period. This can be obtained by weighting the coil, but it is more efficient to use a coil of greater width Of course, where a very long period is necessary, the coil can be made wide, and weighted in addition However, for measurements requiring a ballistic galvanometer of very long period, it has been found more convenient to employ a modification of the ballistic galvanometer known as the fluxmeter. The fluxmeter is a ballistic galvanometer in which the restoring torque has been reduced to a minimum, and the damping made as great as possible When measuring flux with such an instrument and an auxiliary exploring coil, the position of the galvanometer coil follows, almost immediately, any change in flux through the exploring coil. The fluxmeter is so much more convenient to use that it is recommended for all measurements which would otherwise require such a ballistic galvanometer. It is believed by some, that a galvanometer to be used ballistically should be undamped While it is true that an undamped ballistic galvanometer is more sensitive than a critically damped ballistic galvanometer, the critically damped galvanometer is much more convenient Ballistic galvanometers are now available with sufficiently high sensitivity to make it unnecessary to dispense with the damping. Accordingly for convenience, a ballistic galvanometer is recommended for critically damped condition.

consequent throw will not be related in a simple manner to the shunt resistances at the various shunt points because the damping will depend upon the circuit resistance.

If, on the other hand, an Ayrton universal shunt be employed when measuring condenser discharges, the damping constant does not change for the various shunt points, since the galvanometer circuit resistance remains constant for all shunt settings. It suffices, therefore, to determine the galvanometer constant for one shunt ratio and follow the shunt markings for other positions.

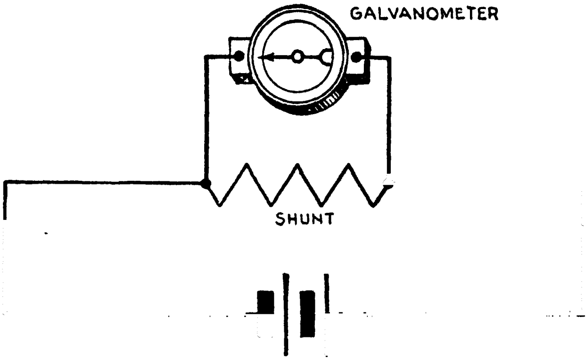


FIG. 1,309.—Diagram showing method of connecting galvanometer shunt. By the use of a shunt the range of measurement of a galvanometer can be greatly increased.

In using a shunted ballistic galvanometer on any other than an extremely high resistance circuit a shunt cannot be used unless the galvanometer constant be determined for the shunt point and circuit conditions to be afterwards employed. To illustrate, in making measurements of magnetic induction, the test or search coil will usually have a low resistance, resulting in a change in the damping constant when the shunted galvanometer is applied to the search coil circuit, and a further change when the shunt switch is moved from one point to another. Even an Ayrton shunt may not be used under these circumstances without determining the galvanometer constant for the particular shunt setting and circuit resistance to be employed in making the induction measurements.

To avoid error from these causes it is customary always to have in series with the search coil the secondary of the mutual inductance to be employed in determining the galvanomoter constant. It is of interest to show the sensitivity of a ballistic galvanometer in two ways. The total quantity of electricity passing through both shunt and galvanometer should be considered.

The other method is to consider the galvanometer throw for a unit quantity of electricity passing through the galvanometer coil. This last

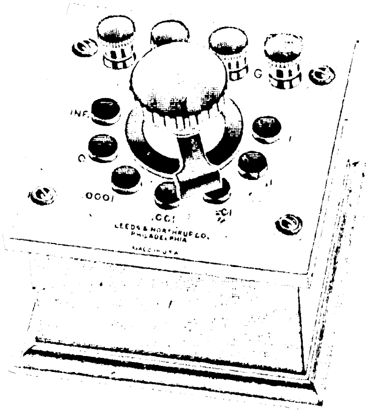


Fig. 1,310.—Ayrton universal shunt. Multiplying powers 1, .1, .01, .001, .0001, 0, and infinity. This type of shunt may be supplied with a total resistance of 3,000, 10,000, 30,000 and 100,000 ohms. ***In selecting*** a shunt the external critical damping resistance of the galvanometer with which the shunt is to be used should be considered. A shunt should be selected which will enable the use of the galvanometer in approximately critically damped conditions. Of course the resistance of the circuit beyond the shunt should be taken into account when making the selection.

NOTE.—***Sensitivity requirements.*** *A galvanometer should have a sensitivity sufficient to permit reading to a degree of precision commensurate with the requirements of the work to be undertaken.* It is usually a matter of simple calculation to determine the required sensitivity. It is not desirable to employ a galvanometer having a sensitivity far greater than the work demands, because this results in working with a galvanometer which is more difficult to use. Another objection arises from the fact that the period is probably longer than necessary because of the higher sensitivity, and as a result the time taken for successive adjustments or readings is relatively longer. An additional disadvantage is that considerable time is likely to be wasted by making too many trials in attempting to obtain too close adjustment. Furthermore, a galvanometer having an unnecessarily high sensitivity is likely to have a less stable zero, particularly since in this case the high sensitivity implies greater departure from zero in making the settings.

method is useful in showing clearly how the shunt affects the sensitivity by reason of its damping.

Galvanometer Shunts.—The sensitiveness of a galvanometer used for measuring current may be reduced to any desired extent by connecting a resistance of known value in parallel with it. Thus, if it be desired to measure a current greater than can be measured directly by the galvanometer, a part of the current can be sent through the resistance or shunt, and the total value of the current calculated.

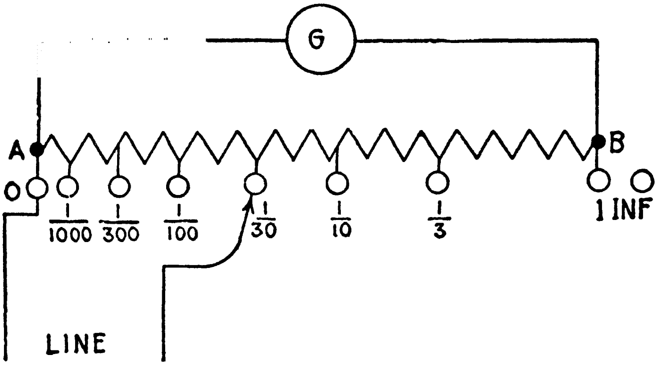


FIG 1,311 —Diagram of a form of universal shunt box for use with galvanometers of widely different resistances The galvanometer, as indicated at G, is connected across the ends of a series of resistances AB The main wires are connected, one to end A, of the series and the other to a traveling point whose position is varied by means of plugs or by a dial switch.

A galvanometer shunt bears a definite ratio to the resistance of the galvanometer, being usually adjusted so that only .1, .01, or .001 part of the current passes through the galvanometer. The degree in which a shunt increases the range of deflection of a galvanometer is called its "multiplying power."

If .1 of the current flowing, passed through the galvanometer and .9 through the shunt, then the current in the circuit would be ten times that through the galvanometer Accordingly the current in the galvanometer must be multiplied by the multiplying power of the shunt to obtain the true value of the current in the circuit

In order to determine the resistance necessary to be used with a certain galvanometer, the resistance of the latter ***is to be divided by the multiplying power desired**, less **one.***

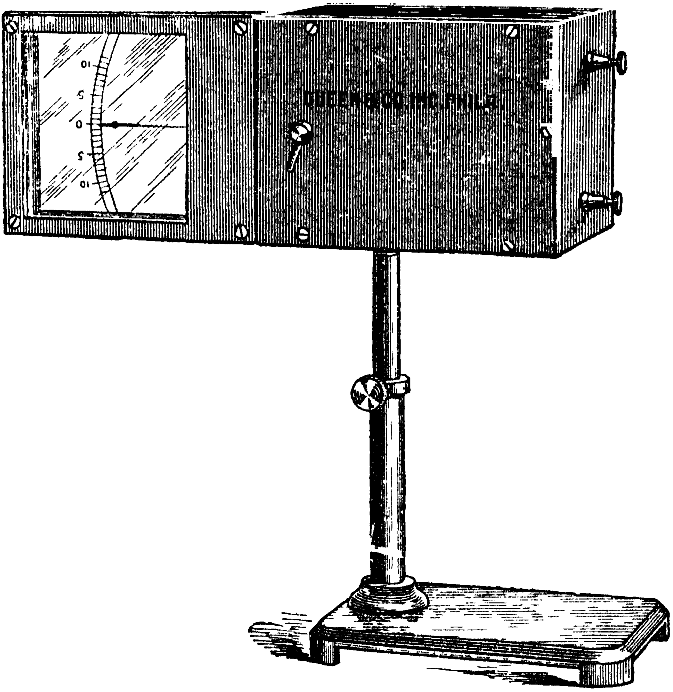


FIG 1,312 —Queen projection or lecture table galvanometer, used also by manufacturers as a current detector on work benches to note if circuit winding, coil, etc be complete The galvanometer is a pivot and jewel type D'Arsonval and requires no leveling or adjusting The telescope support allows for adjusting the height The scale is etched in glass

Example.—What must be the resistance of a shunt for a galvanometer of 2,000 ohms resistance where only one-fifth of the current is to pass through the galvanometer?

The multiplying power less one is

$$5-1=4$$

and the required resistance is

$$2{,}000 \div 4 = 500 \text{ ohms}.$$

Damping.—This relates to the checking or reduction of oscillations. Thus, a galvanometer is said to be damped when so constructed that any oscillations of the pointer which may be started, rapidly die away. Galvanometers are frequently provided with damping devices for the purpose of annulling these oscillations, thus causing the moving part to assume its final position as quickly as possible.

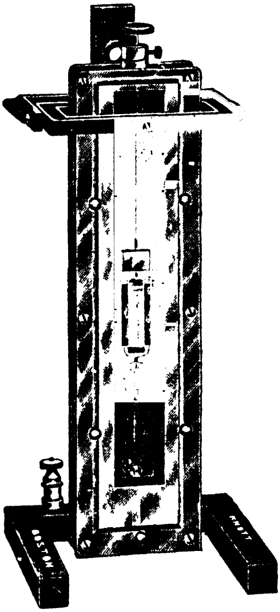


Fig. 1,313.—Knott self-leveling D Arsonval galvanometer, 600 megohm sensibility, designed especially for advanced laboratory work It can be used either as a wall or table instrument is both self-centering and self leveling The instrument is hung from universal gimbals, so that both magnet and coil are always in correct relation. Resistance 400 ohms

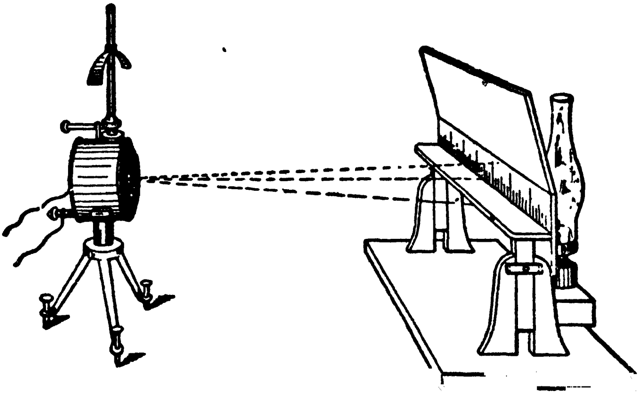


FIG. 1,314.—Thompson galvanometer with mirror reflecting system for reading the deflections of a galvanometer needle by the movements of a spot of light reflected from a mirror attached to the needle or movable magnetic system.

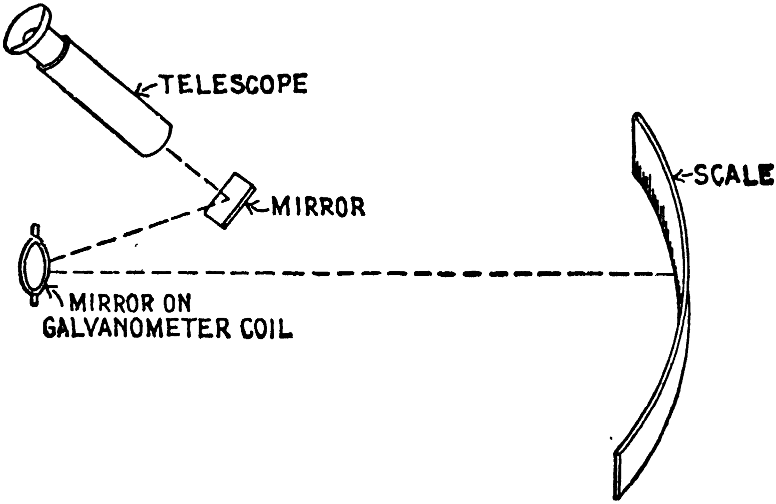
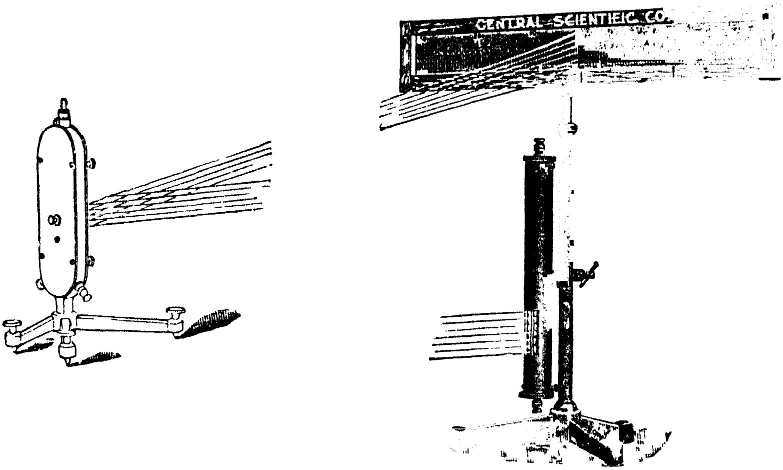


FIG. 1,315.—Telescope method of reading galvanometer deflections by reflection of scale reading in mirror. Here two mirrors are used, but in most cases the telescope is pointed directly toward the mirror on the galvanometer shown in fig. 1,314, because the two mirror system, as illustrated in the figure, is used on portable galvanometers since it is the more compact.

Sometimes the instrument is fitted with a damping coil, or closed coil so arranged with respect to the moving system that the oscillations of the latter give rise to electric currents in the closed coil, whereby energy is dissipated. Again, air vanes are employed, but anything in the nature of solid friction cannot be used.

Use of Mirrors in Galvanometers.—In order that small currents may be measured accurately, some means must be provided to easily read a small deflection of the needle. Accordingly, it is desirable that the pointer be very long so that a large number of scale divisions may correspond to small deflections. In construction, since sensitive galvanometers must be made with the moving parts of little weight, it would not do to use a long needle, hence a ray of light is used instead,



FIGS 1,316 and 1,317 —Galvanometer lamp and scale for individual use The scale is etched on a ground glass strip 6 centimeters wide by 60 centimeters long with long centimeter divisions and short millimeter divisions the entire length, reading both ways from zero in the center It is mounted in an adjustable wooden frame A straight filament lamp (110 volts) is enclosed in a metal hood japanned black to cut out all reflected light. This form of filament makes a single brilliant line on the scale, enabling closer readings than the "spot of light" arrangement. The lamp hood is adjustable to any desired height on the support rod.

which is reflected on a distant scale by a small mirror attached to the moving part.

In the Thompson mirror reflecting galvanometer, as shown in fig. 1,314, a small vertical slit is cut in the lamp screen below the scale, and the ray of light from the lamp, passing through the slit, strikes the mirror which is about three feet distant, and which reflects the beam back to the scale.

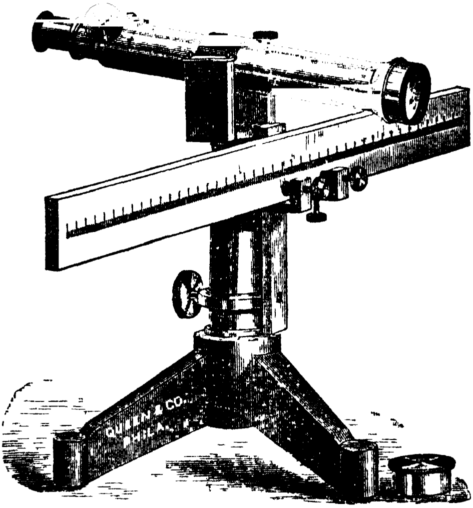
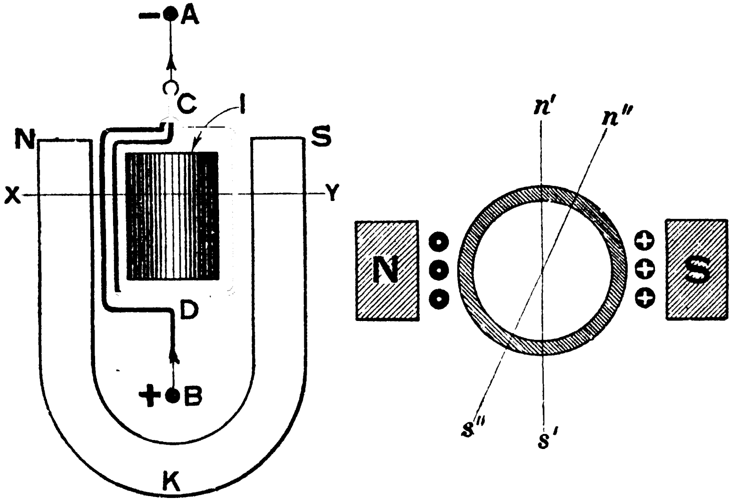


FIG. 1,318 —Reading telescope This arrangement is utilized to measure the deflections of a galvanometer having suspended mirror moving system. *It consists of* a reading telescope mounted as illustrated with a millimeter scale, having a length of 50 centimeters In use, the image of the scale is seen in the galvanometer mirror through the telescope The eye piece of the telescope has a cross hair which acts as a reference line so that by noting the particular division on the scale when the galvanometer is at rest, the amount of deflection can be readily observed when the galvanometer is deflected The instrument has all the necessary adjustments to set it up quickly and for bringing the cross hair and scale in focus. It is generally placed at a distance of one meter from the galvanometer mirror.

It should be noted that the angle between the original ray of light and the reflected ray is twice the angle of the deflection of the mirror; the deflections of the ray of light on the scale, however, are practically proportional to the strength of currents through the instrument.

The mirror arrangement as shown in fig. 1,314, requires a darkened room for its operation, but such is not necessary when a telescope is used as in fig. 1,315. Here the scale readings are reflected in the mirror and their value observed by the telescope without artificial light.

D'Arsonval Galvanometer.—This instrument has a movable coil in place of a needle, and its operation depends upon the principle that if a flat coil of wire be suspended with its axis perpendicular to a strong magnetic field, it will be deflected whenever a current of electricity passes through it.



Figs. 1,319 and 1,320.—Diagrams showing essential features of construction and principle of operation of D'Arsonval galvanometer.

Ques. Describe the construction of a D'Arsonval galvanometer.

Ans. The essential features are shown in figs. 1,319 and 1,320. The coil, which is rectangular in section is wound upon a copper form, and suspended between a permanent magnet by fine wires to the points A and B. The magnet has its poles at N and S. It has a soft iron cylinder fixed between the poles in order to intensify the magnetic field across the air gaps in which the coil moves.

Ques. Explain its operation.

Ans. An enlarged horizontal cross section of the galvanometer on line XY, is shown in fig. 1,320. The current is flowing in the coil as in fig. 1,319, up on the left side and down on the right. The position of the coil when no current is flowing is indicated by *n′ s′*. By applying the law of mutual attraction

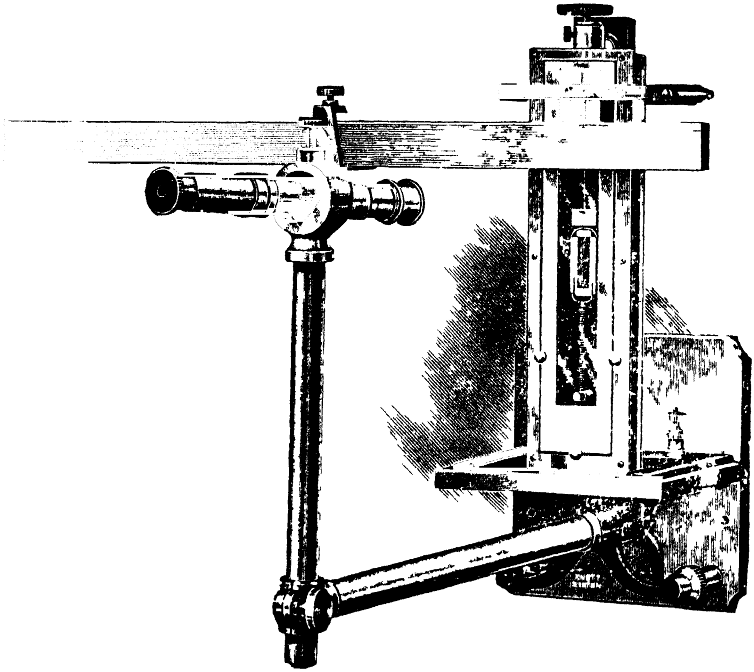


Fig 1,321 —Knott self leveling wall galvanometer

between magnetic poles, it is seen that when the current is applied, the poles developed at $n' s'$, will move into the position $n'' s''$, as shown in fig. 1,320.

Ques. How is the coil affected by a change in the direction of the current?

Ans. The polarity of the coil is reversed and consequently the direction of the deflection.

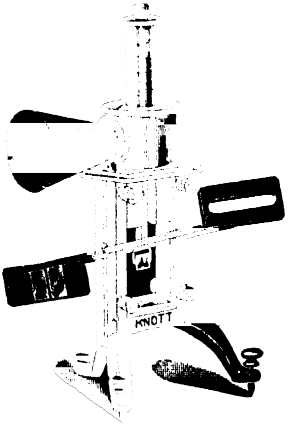


FIG. 1,322.—Knott radio micrometer heat indicator. *It contains* the fundamental parts of the D Arsonval galvanometer, but with the moving coil replaced by a sensitive thermoelectric couple. A candle flame 50 ft. distant will cause a marked deflection. The deflecting horn is mounted on a movable ring, so that the heat can be received from either side only. The heat from the body of the observer therefore cannot affect the readings.

Ques. Upon what does the sensitiveness of the instrument depend?

Ans. Upon the strength of the field of the permanent magnet, the number of turns in the suspended coil, and the torsion of the wires by which it is suspended.

Ques. When is this galvanometer called "dead beat"?

Ans. When the construction is such that the moving part comes quickly to rest without a series of diminishing vibrations.

Ques. What causes this?

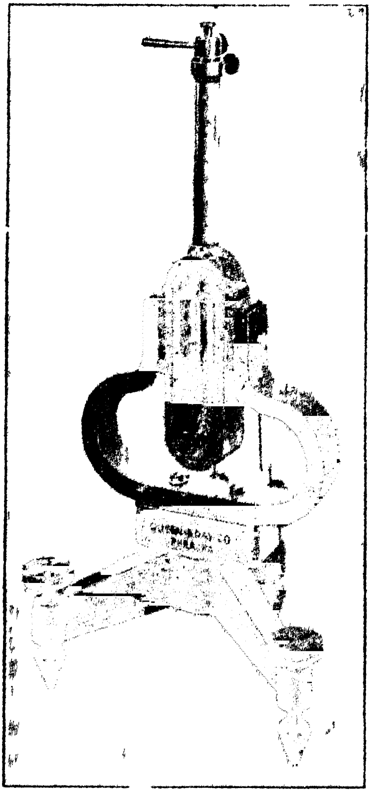
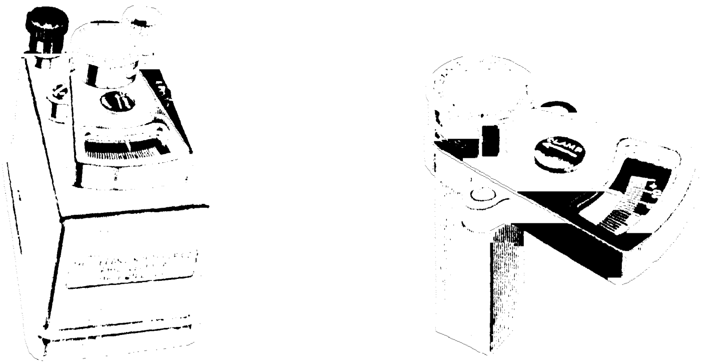


FIG. 1,323.—Queen high sensitivity galvanometer ***The coil system*** is contained in its case as a separate unit, so that any number of systems can be placed in the same magnet The damping is attained by the induced currents set up in a closed copper circuit on the coil This current is removable thereby making the system dead beat or ballistic The deflections, whether the damping circuit be on or off the coil are proportional to the current passed through the coil, or to the quantity of electricity discharged through when used ballistically The coil is protected by means of a clamp operated from the back of the coil case It is designed so as to prevent too much pressure being exerted on the coil

Ans. The instrument is made dead beat by winding the coil on a copper or aluminum frame, so that when in operation, currents are induced in the frame by the motion of the coil in the magnetic field; these currents oppose the motion of the coil.

Ques. For what service is the D'Arsonval galvanometer adapted?

Ans. It is desirable for general use as it is not much affected by changes in the magnetic field. It may be made with high enough period and sensitivity to be satisfactory as a ballistic instrument, but for extreme sensitivity an instrument of the astatic type is more generally used.



Figs. 1,324 and 1,325.—Leeds and Northrup portable galvanometer, pointer type with removable system. This type has sufficient sensitivity for Wheatstone bridge work to accuracies of $^1/_{10}$%; for potentiometer measurements to .05 millivolt; and for a variety of purposes for which reflecting instruments might be supposed to be required. System, pointer and scale is contained in removable interchangeable unit. Scale, 15 mm. divisions either side of a central zero, viewed through glass covered aperture. Zero adjustment provided by screw on top suspended system housing. Fig. 1,324 shows galvanometer and fig. 1,325 system.

Galvanometer "Constant" or "Figure of Merit."—In order that a galvanometer shall be of value as a measuring instrument, the relation between the current and the deflection produced by it must be known. This may be obtained experimentally by determining the value of the current required to produce one scale division. The galvanometer constant then may be defined as *the resistance through which the galvanometer will give a deflection of one scale division when the current applied is at a pressure of one volt.*

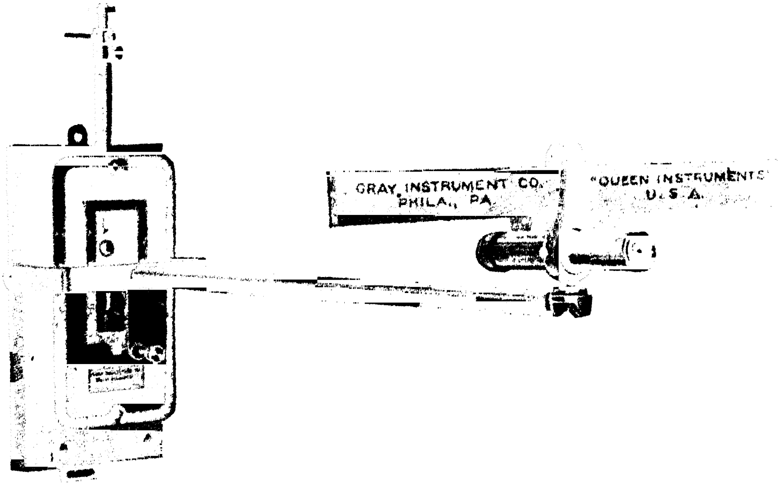


FIG. 1,326.—Queen wall type D'Arsonval galvanometer designed for general work in electrical measurements. The instrument can be leveled by means of the side gimbal screws and the screw at the bottom. The pole pieces have been shaped in relation to the shape of the coil so as to produce proportional deflections. The scale is curved so as to make the deflection proportional to the angle of deflection. It is mounted upon an aluminum back controlled by a rack and pinion for zero adjustment. The scale is divided into millimeters with 250 dimensions in black on one side and 250 dimensions in red on the other side of zero.

Accordingly, the deflection as indicated on the scale must be multiplied by its constant or figure of merit, in order to obtain the correct reading. If the scale readings be not directly proportional to the quantity to be measured, the law of the instrument must also be considered.

Thus in a tangent galvanometer as previously explained

$$I = K \tan \phi$$

where I = current, ϕ, the deflection or scale reading, and K, the galvanometer constant.

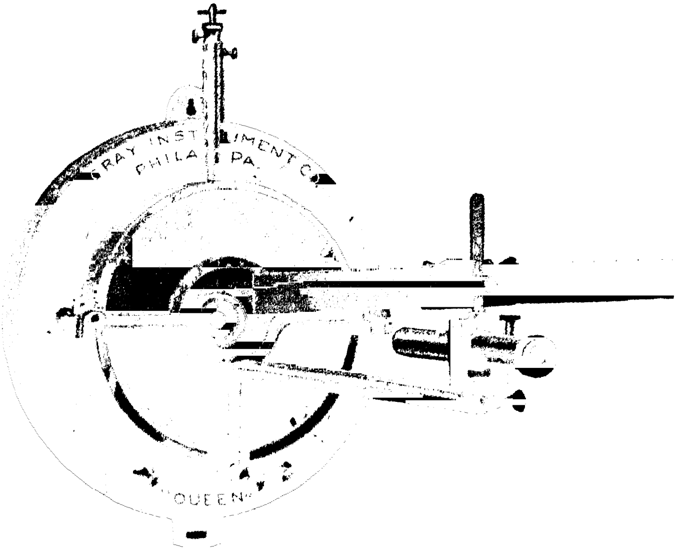


FIG. 1,327.—Queen type S wall D'Arsonval galvanometer designed for use in both educational and commercial laboratories.

When it is essential that the total resistance of the circuit should not be altered by an alternation of the galvanometer shunt, a compensating box should be used which automatically inserts a resistance for each shunt in series with the shunted galvanometer to bring the total resistance up equal to the unshunted value. Thus the current in the main circuit is not altered.

Sensitivity.—There are four convenient definitions of this characteristic, involving some statement of the electrical conditions required to secure a standard deflection.

Current sensitivity
Megohm sensitivity
Voltage sensitivity
Ballistic sensitivity

Current sensitivity.—This is *the current required to give the standard deflection.*

In any d'Arsonval galvanometer it is *the current flowing through the moving coil that causes the deflection,* and all other expressions of galvanometer sensitivity are derived from the current sensitivity.

Megohm sensitivity.—This is *the number of megohms resistance that must be placed in series with the galvanometer in order that from an impressed e.m.f. of one volt there shall result the standard deflection.*

Inasmuch as the galvanometer coil resistance is usually negligible in comparison with the total resistance in series, the megohm sensitivity is only another way of stating the current sensitivity. The number representing the megohm sensitivity is the reciprocal of the number representing the current sensitivity. The megohm sensitivity is the constant usually stated for galvanometers to be used for measuring insulation resistance.

Voltage sensitivity.—This is *the voltage that must be impressed on the circuit made up of the galvanometer coil and the external critical damping resistance, in order that there shall result the standard deflection.* The voltage sensitivity is equal to the product of the current sensitivity and the total resistance in circuit. It is the constant usually stated for low resistance galvanometers to be used for detecting very small *e.m.f.'s* such as those generated by thermo-couples.

Ballistic sensitivity.—This is *the quantity of electricity that must suddenly be discharged through the galvanometer in order that there shall result the standard deflection.*

It is the constant usually given for galvanometer to be used ballistically for the measurement of brief discharges from condensers or inductances. The ballistic sensitivity constants refer to the undamped condition of the galvanometer. The sensitivity of a ballistic galvanometer when critically damped is about one third of the undamped sensitivity.

The third definition, the micro-volt sensitivity, is usually employed with low resistance galvanometers. The first and second are used interchangeably with high resistance galvanometers, and in the same galvanometer are numerically equal.

External Critical Damping Resistance.—This is the resistance which must be placed in series or in parallel with the galvanometer to produce the critically damped condition.

FIG. 1,328.—Queen portable D'Arsonval galvanometer. The deflections are proportional to the current and the scale has 30 divisions each side of the center. A zero adjustment is provided.

Period.—The period usually stated for a galvanometer is the full undamped period, which is the time in seconds elapsing between two successive passages in the same direction through the position of rest. It is customary to take the period of critically damped galvanometer as equal to its undamped period, for while the critically damped period is theoretically infinite, practically, a critically damped deflection is within about 1.5% of its final position in the undamped periodic time. While the full undamped period is stated for ballistic galvanometers, the quarter period

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NOTE.—*The Bureau of Standards* recommends including the external critical damping resistance in the galvanometer circuit when calculating or determining the voltage sensitivity. Some foreign makers specify the voltage sensitivity at the terminals of the galvanometers without the critical damping resistance in series. This latter sensitivity may be several times the former. This fact should be borne in mind when selecting a galvanometer.

(or the time for the initial deflection away from zero) is of principal interest in ballistic measurements. When critically damped, the time for the quarter period is obtained by dividing the undamped quarter period by 2×3.1416.

TEST QUESTIONS

1. *What is a galvanometer?*
2. *What is a galvanoscope and how does it differ from a galvanometer?*
3. *What effect has a neighboring current upon a magnetic needle?*
4. *How does a galvanometer indicate the direction and strength of the current?*
5. *How should a galvanometer be set up before using?*
6. *What is a "sensitive" galvanometer?*
7. *Upon what does the sensitivity depend?*
8. *What is the difference between a short coil and a long coil galvanometer?*
9. *Explain the operation of short and long coil galvanometers.*
10. *Give the two general classifications of galvanometers.*
11. *Name six kinds of galvanometers.*
12. *What is an astatic galvanometer and for what use is it adapted?*
13. *Does the astatic galvanometer give correct readings for different values of the current?*
14. *Describe a tangent galvanometer, and its use.*

15. *Upon what does the sensitivity of the tangent galvanometer depend?*
16. *How may the tangent galvanometer be used as an ammeter?*
17. *Explain the tangent law; give mechanical explanation of this law.*
18. *How is the tangent galvanometer constructed to give direct reading?*
19. *What is the disadvantage of the tangent galvanometer?*
20. *Describe the sine galvanometer and its use.*
21. *How is current strength measured with the sine galvanometer?*
22. *What is the position of instability of the sine galvancmeter?*
23. *What advantage has the sine galvanometer over the tangent galvanometer?*
24. *Define the term "damping effect."*
25. *What is the external critical damping resistance?*
26. *Define the term "period" and what are the period requirements?*
27. *Describe the differential galvanometer and its use.*
28. *What is the method of comparing currents with the differential galvanometer?*
29. *How are the differential coils adjusted?*
30. *Describe the ballistic galvanometer and its use.*
31. *What is a "kick"?*
32. *Describe the shunted ballistic galvanometer.*
33. *What are galvanometer shunts and how are they used?*

34 *Define the term "dambing."*

35. *How are mirrors used in galvanometers?*
36. *Explain the construction and principle of the D'Arsonval galvanometer.*
37. *When is the D'Arsonval galvanometer called "dead beat"?*
38. *What is the galvanometer "constant" or "figure of merit"?*
39. *Give four definitions for sensitivity.*

CHAPTER 38

D. C. Indicating Instruments

The various devices considered in this chapter for indicating current, pressure and electrical energy are known as:

1. Ammeters;
2. Volt meters;
3. Electro-dynamometers;
4. Watt meters.

An ammeter is simply *a commercial form of galvanometer so constructed that the deflection of the needle indicates directly the strength of current in amperes.*

A good ammeter should have a very low resistance so that very little of the energy of the current will be absorbed; the needle should be dead beat, and sufficiently sensitive to respond to minute variations of current.

According to the principle of operation, ammeters and volt meters are classified as:

1. Moving iron;
2. Moving coil;
3. Solenoid or plunger;
4. Magnetic vane;
5. Hot wire;
6. Electrostatic;

7. Astatic;
8. Inclined coil;
9. Fixed and movable coil.

Again, they are divided according to their use into two classes:

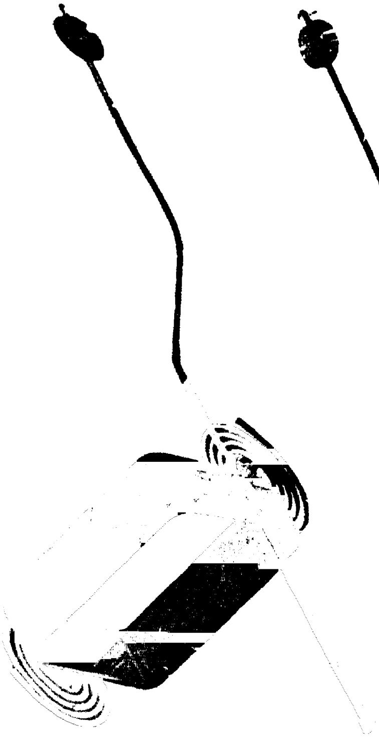


Fig. 1,329 —Moving element of Brown-Keystone instruments, weight 1.2 grams

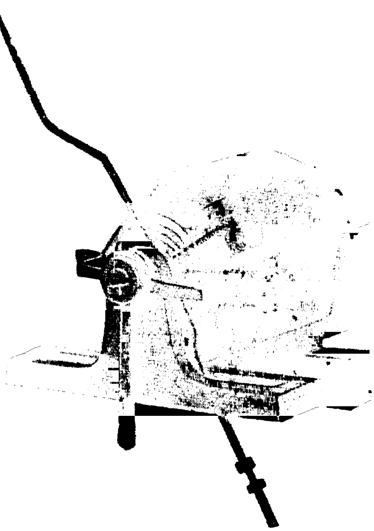


Fig 1,330 —Moving element of Brown Keystone instruments assembled in bearing. The moving element consists of coil, counterpoise and pointer The mechanical connections are made by means of screws and steady pins In order to adjust for slight set or subset of spring under long use a zero adjuster is provided by means of which this set can be connected and the pointer brought back to zero.

1. Portable type;
2. Switchboard type.

Milli-ammeters or milli-volt meters are instruments in which the scale is graduated to read directly in thousandths of an ampere or thousandths of a volt respectively.

Ques. Describe the moving iron type instrument.

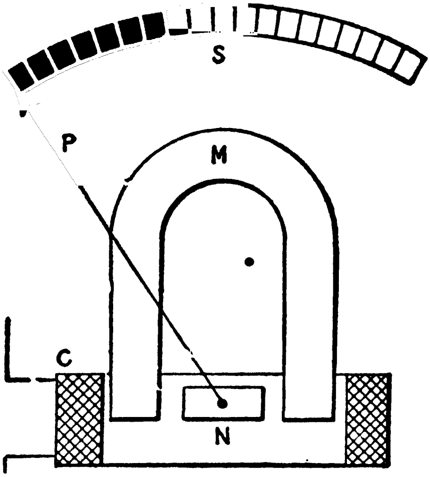
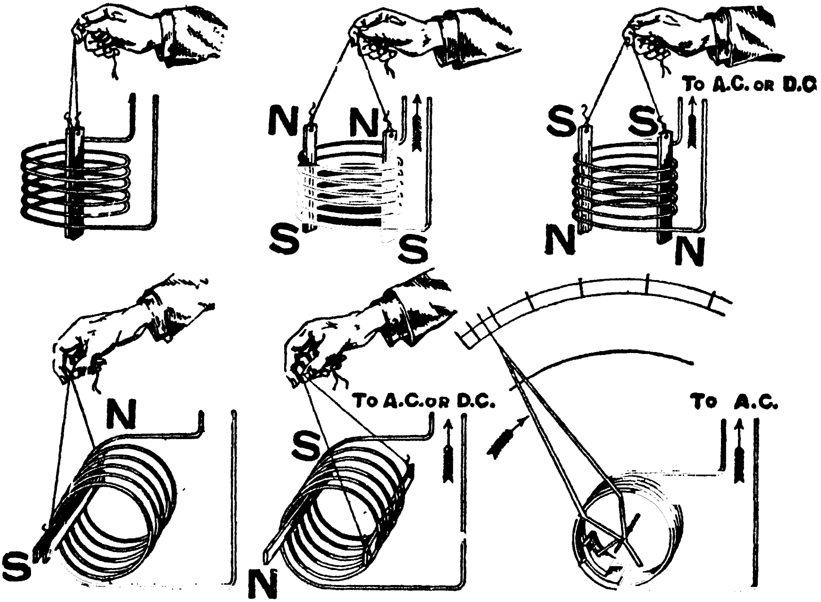


FIG. 1,331.—Moving iron type instrument. The essential parts are: N, soft iron needle; C, coil; M, permanent magnet; P, pointer; S, scale. Current passing through the coil acts on the needle, causing it to turn against the restraining force due to the influence of the permanent magnet.

Ans. The arrangement of the working parts is shown in fig. 1,331. A soft iron needle is pivoted at N, inside of a coil C, and is held out of line with the axis of the coil by means of a permanent magnet M, when the instrument is idle. In this position, the pointer P, which is attached to the needle, stands at the zero mark of the scale S.

If a current be passed through the coil, magnetic lines of force are set up in its center, which tend to pull the needle into line with them, and therefore with the axis of the coil. This pull is resisted by the permanent magnet M, and the amount of deflection of the needle from the zero position depends upon the strength of the current or the voltage according to whether the coil is wound to indicate amperes or volts.

Ques. What is the principle of the moving iron type instrument?



Figs. 1,332 to 1,337.—Principle of moving iron repulsion instruments. If direct current be sent through the two small pieces of iron suspended vertically within a solenoid by thread as in fig 1,332, they will become magnetized and since they are in the same magnetic field both will be affected the same, and will repel each other as in fig. 1,333. If the current be sent through the solenoid in the opposite direction the result will be the same. Next if the coil be laid on its side and the two pieces of iron be placed within it horizontally as in fig. 1,335, one fixed and the other free to move and a current be passed through the solenoids the two pieces of iron will repel each other If an *a c.* be used instead of *d. c.* and it reverse with sufficient frequency, the polarity of the two pieces of iron will reverse in step with the current and they will repel each other as before. Hence on employing this principle in instrument construction two curved pieces of iron are used, one fixed and the other pivoted so that it will rotate when electrically repelled from the fixed iron as in fig. 1,337. A pointer attached to the movable iron moves over a graduated scale

Ans. This type of instrument depends for its action upon *the pull of flux in endeavoring to reduce the reluctance of its path.*

This pull is proportional to the product of the flux and the current, and so long as no part of the magnetic circuit becomes saturated, the flux is proportional to the current, hence the pull is proportional to the square of the current to be measured.

Ques. Describe a moving coil instrument.

Ans. This type of instrument is shown in fig. 1,338. It consists of a moving coil C, to which is attached a pointer P, and which is pivoted between the poles of a permanent magnet M. The coil moves between these poles and a fixed soft iron core K, and is held in the normal position by two spiral springs A, above and below the coil. The springs also serve to make electrical connection with the coil C.

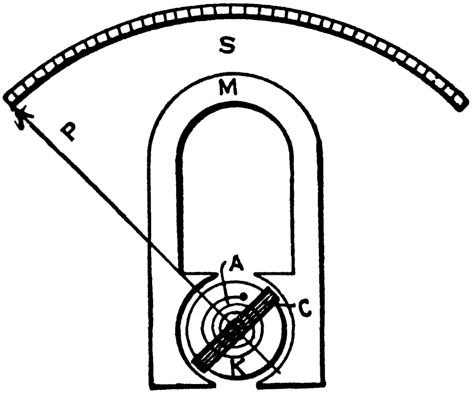


Fig. 1,338.—Moving coil type instrument. The essential parts are: A, spiral spring; C, coil; K, soft iron core; M, permanent magnet; P, pointer; S, scale. Current passing through the coil causes the moving system to turn against the restraining force due to the influence of the permanent magnet.

When a current passes through the coil, magnetic lines are set up in it which are at an angle to those passing from one pole of the permanent magnet to the other. The lines of force, which formerly passed from one pole of the magnet to the other by straight lines or by short curved ones, are "stretched" on account of the field produced by the current in the coil, and, in trying to shorten themselves, tend to twist the coil through an angle. This tendency to move is resisted by the two spiral springs, hence the coil moves until equilibrium is established between the two opposing forces.

The amount of deflection of the pointer depends, either upon the current strength. or the voltage according to the winding of the coil.

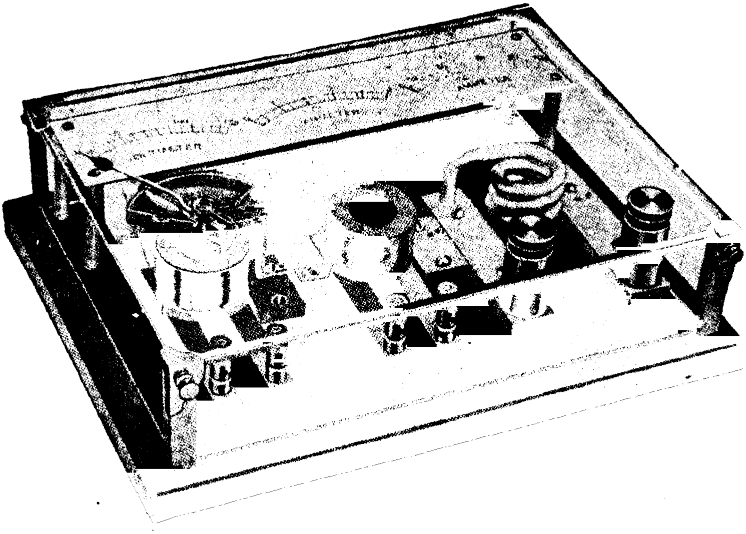
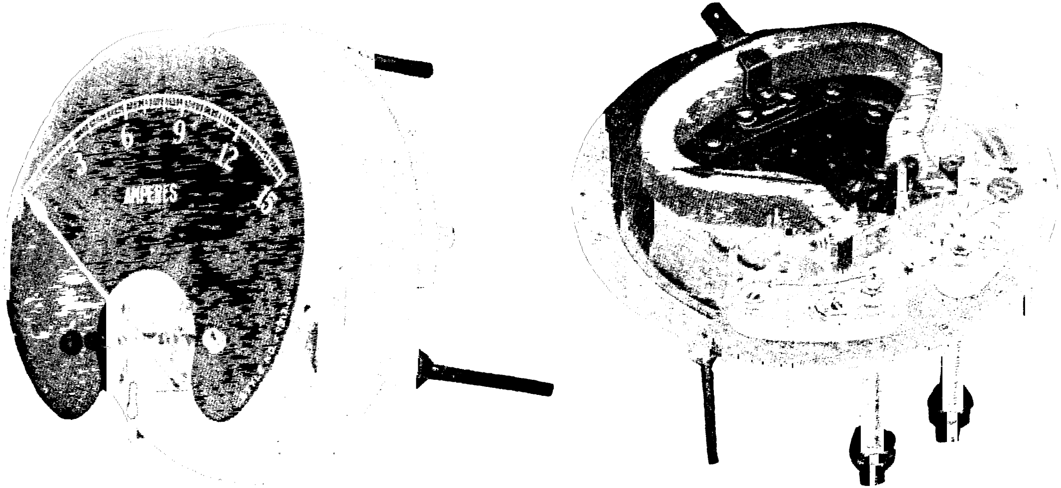


FIG. 1,339.—Reliance dissectable volt meter and ammeter for *d. c.* and *a. c.* This meter was designed to show in the simplest form possible the similarity in construction of a volt and ampere meter of the magnetic vane principle. As the difference of volt meters and ammeters of this type is in the series spool or coil only, the moving element is so arranged that it may be easily removed from the volt meter coil and mounted in either the low reading ammeter coil or the one of greater carrying capacity, or vice versa. The series coil of the volt meter is wound with a very fine wire and a resistance put in series to adjust same for the voltage or scale marking. The size of wire with which the ammeter coils are wound must be of the carrying capacity for which the scale is drawn. A very distinct comparison of the three ampere coil and the one hundred ampere coil is here shown.



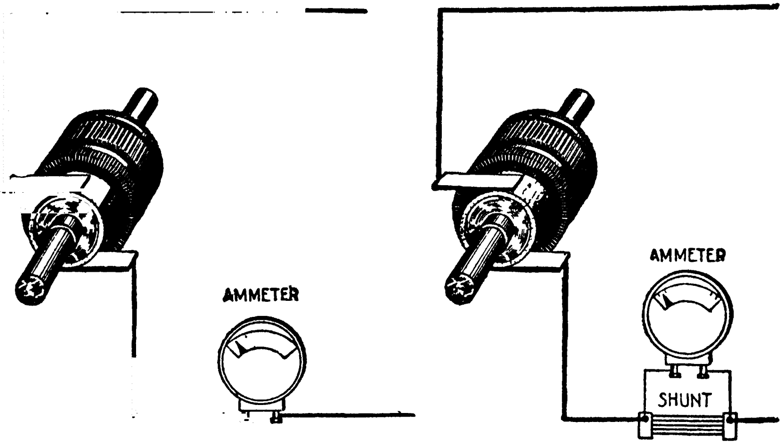
FIGS. 1,340 and 1,341.—Westinghouse, D'Arsonval type instruments. Fig. 1,340, ammeter with cover removed, fig. 1,341, volt meter with cover and dial removed.

Ques. How does the winding differ in ammeters and volt meters?

Ans. An ammeter coil consists of a few turns of heavy wire (when designed to carry the full current), while a volt meter coil is wound with many turns of fine wire. Thus, the ammeter is of low resistance, and the volt meter of high resistance.

Ques. Why is a high resistance coil used with a volt meter?

Ans. As actually constructed, most volt meters are simply special forms of ammeter. From Ohm's law, the current through a given circuit equals the pressure at its terminals divided by its resistance. Hence, if a high resistance be connected in series with a sensitive ammeter that will measure very small currents, then the current passing through the circuit is directly proportional to the voltage at its terminals, and the instrument may be calibrated to read volts.



Figs 1,342 and 1,343 —Connections for series and shunt ammeters When the construction is such that all the current passes through the instrument, it is connected as in fig 1,342, but where the instrument is designed to take only a fraction of the current, it is connected across a shunt, as in fig 1,343, a definite proportion of the current passing through the instrument and the remainder through the shunt

Ques. Into what two classes may ammeters be divided?

Ans. They are classed as series or shunt according to the way they are designed to be connected with the circuit.

Ques. What determines the mode of connecting ammeters?

Ans. When the wire of the ammeter coil is large enough to carry the whole current, it is connected in the circuit *in series* as shown in fig. 1,342. If, however, the wire be small, the instrument is connected *in parallel* with a shunt of low resistance, so that it only carries a small part of the current, as in fig. 1,343.

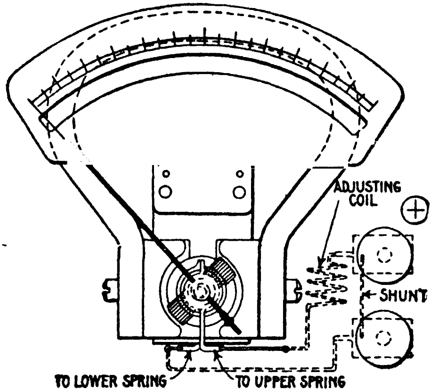


FIG. 1,344.—Weston ammeter, view showing shunt enclosed within the instrument. Weston instruments are direct reading and dead beat. Although the scales have practically uniform divisions, it is not assumed in the calibration that they are uniform, and the scales are not printed or engraved. The method of calibration consists in laying out each large division of the scale by comparing the instrument with a standard, and then inking in the division lines so found. The smaller divisions between the large ones are then equally spaced and marked by a mechanical method.

For circuits which carry large currents, the shunt connection is always used, because otherwise the coil of the ammeter would have to be very heavy and the instrument correspondingly bulky.

Ques. How are shunt ammeters arranged to correctly measure the current?

Ans. The coil is arranged so that a definite proportion of the whole current passes through it.

A large conductor of low resistance is connected directly between the two terminals or binding posts of the instrument, the coil is connected as a shunt around a definite part of this main conductor, then, since the two are connected in parallel and each branch has a definite resistance, the current divides between the two branches directly in proportion to their relative conductivities, or inversely according to their resistances. The coil, therefore, takes a definite part of the whole current, and the force moving it and its pointer away from the zero position is directly proportional to the whole current Hence, by providing a proper scale, the value of the entire current will be indicated

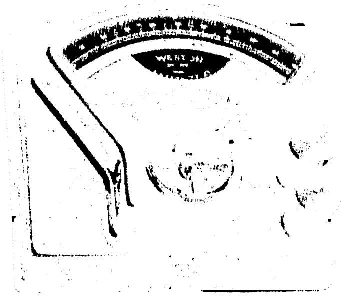


FIG 1,345 —Weston portable standard ammeter with self contained shunts The pointer is knife edged and each instrument is equipped with a zero correcting device

Ques. How is a volt meter connected?

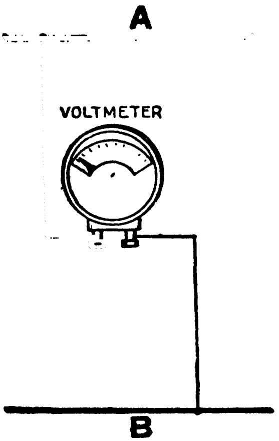
Ans A volt meter is always connected to the two points, whose difference of pressure is to be measured.

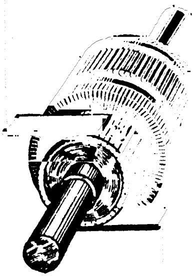
NOTE —*Instrument errors on rectified circuits.* If an instrument of the first class and one of the second be connected in series with a rectified current, their indications will differ according to the relation the ripple bears to the total current and the form factor of the ripple This discrepancy may be in the neighborhood of 2 to 5 per cent under commercial operating conditions as shown by the actual tests The upper limiting value of the error would be equal to the form factor, or ratio between the root mean square and the average value of the wave In the case of a sine wave this amounts to 1 11, causing an error of 11 per cent in the reading If it be desired to measure the watts taken by a translating device of any character, a dynamometer type of wattmeter should be used in preference to any other By so doing, no errors due to rectified current peculiarities will be introduced.

For instance, to measure the voltage between the two sides A and B, of the circuit shown in fig. 1,346, one terminal of the volt meter is connected to wire A, and the other to wire B. If the "drop" or difference in voltage through a certain length of wire L, of a circuit, as from A to B, in fig. 1,347 is to be determined, one terminal of the volt meter is connected to A, and the other to B.

In a similar manner is found the drop through a lamp.

Ques. What is the difference between a volt meter and an ammeter?





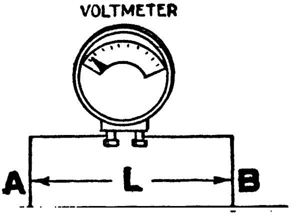


Fig. 1,346.—Volt meter connection for measuring the pressure in an electric circuit. The volt meter is connected *in parallel* in the circuit at the point where the voltage is to be measured.

Fig. 1,347.—Volt meter connection for measuring the "drop" or fall in voltage in a certain length of wire, as for instance, the length between the points A and B. The volt meter is *shunted* between the two points whose pressure difference is to be measured.

Ans. A volt meter measures pressure, while an ammeter measures current. As actually constructed, most volt meters are simply special forms of ammeter.

Ques. Explain the term "calibrate."

Ans. To calibrate a measuring instrument is to determine the variations in its readings by making special measurements or by comparison with a *standard.*

Ques. Describe a solenoid or plunger ammeter.

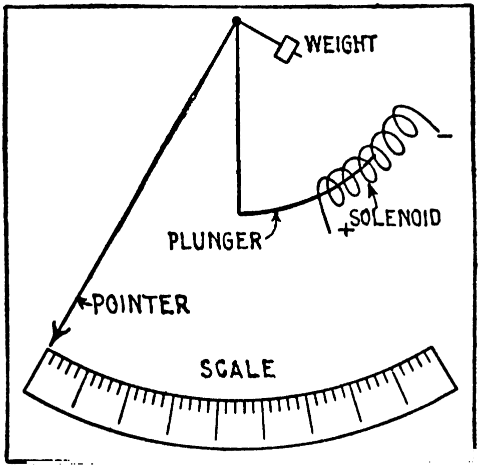


Fig 1,348 —Plunger type instrument The current to be measured passes through the solenoid producing a magnetic effect on the soft iron plunger which tends to draw it into the coil, and thus causes the pointer to move over the graduated scale The distance the rod moves depends on the value of the restraining force (which may be springs or gravity), the coil winding, and strength of current The winding consists of a few turns of heavy wire for an ammeter, and a large number of turns of fine wire when constructed as a volt meter Since the iron has a certain amount of residual magnetism, the deflection with smaller following large currents is more than would be produced by the same current following a smaller one The instrument therefore is less reliable than the usual types

Ans. This type consists of a "plunger" or soft iron core arranged to enter a solenoid.

Current being passed through the wire of the solenoid causes the core to be more or less attracted against a restraining force of gravity or springs

A pivoted pointer attached to the core indicates the current value on a graduated dial as shown in fig. 1,348.

Ques. What are the objections to plunger instruments?

Ans. They are not reliable for small readings, and are readily affected by magnetic fields.

Ques. Describe a magnetic vane instrument.

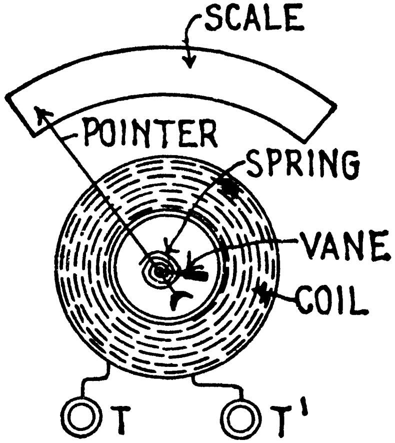


Fig. 1,349.—Magnetic vane instrument. A soft iron vane, eccentrically pivoted within a coil carrying the current to be measured, is attracted toward the position where it will conduct the greatest number of magnetic lines of force against the restraining force of a spring or equivalent.

Ans. It consists of a small piece of soft iron or *vane* mounted on a shaft that is pivoted a little off the center of a coil as shown in fig. 1,349.

The principle upon which the instrument works is that a piece of soft iron placed in a magnetic field and free to move will move into such position as to conduct the maximum number of lines of force. The current to be measured is passed around the coil producing a magnetic field through the center of the coil. The magnetic field inside the coil is strongest near the inner edge, hence, the vane will move against the restraining force of a spring so that the distance between it and the inner edge of the coil will be as small as possible. A pointer, attached to the vane shaft moves over a graduated dial.

Ques. Describe an inclined coil instrument.

Ans. As shown in fig. 1,350, a coil carrying the current, is mounted at an angle to a shaft to which is attached a pointer.

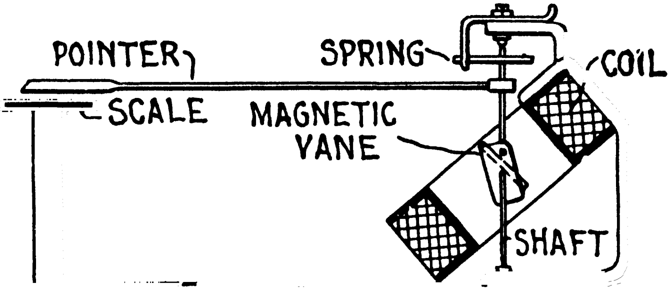


FIG. 1,350.—Thomson inclined coil ammeter. *It is constructed* on the magnetic vane principle in which an iron vane is attracted by the magnetic field due to the coil, so as to turn itself parallel with the axis of the coil, the latter being inclined with respect to the axis of the vane. The volt meter of this type has a similarly placed stationary coil, but in place of the iron vane, is provided with a moving coil in series with the other coil. The restraining force in each case being that due to springs. Figs. 1,351 and 1,352 show the actual construction of inclined coil instruments.

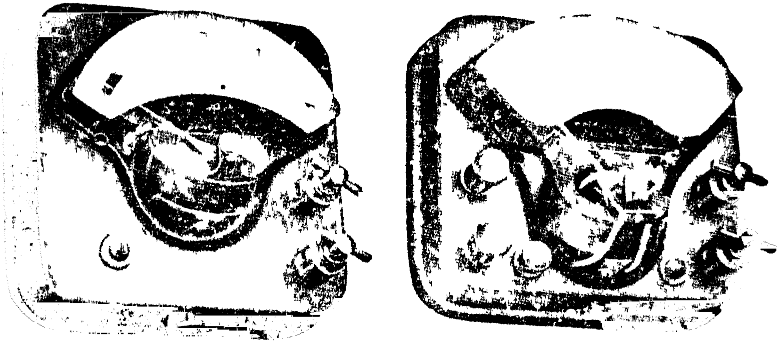
A bundle of iron strips is mounted on the shaft. A spring restrains the shaft and holds the pointer at the zero position when no current is flowing.

When a current is passed through the coil, the iron tends to take up a position with its longest sides parallel to the lines of force, which results in the shaft being rotated and the pointer moved on the dial, the amount of movement depending upon the strength of the current in the coil.

The coils for large sizes are generally wound with a few turns of flat insulated copper ribbon. The instruments are adapted to either direct or alternating currents but are recommended for alternating currents.

Ques. What is the principle of the hot wire instrument?

Ans. Its action depends upon the heating of a conductor by the current flowing through it, causing it to expand and set in motion an index needle or pointer, the movements of which, by calibration, are made to correspond to the pressure differences producing the actuating currents.



Figs 1,351 and 1,352 —Thomson inclined coil portable indicating instruments Fig 1,351, ammeter type P, interior, fig 1,352, watt meter, type P, interior These instruments, though primarily designed for use on alternating current circuits, may also be used on direct current circuits, by making reversed readings and taking the mean as the true indication The volt meters and watt meters are constructed on the dynamometer principle and the ammeters, on the magnetic vane principle The volt meters and watt meters are provided with a contact key which may be locked in position, enabling the instruments to be left constantly in circuit The movements of the pointer are damped by means of an air vane; there is also a friction damping device operated by a small button to check excessive oscillations of the pointer The inclined coil instruments are so designed that the torque is sufficiently high to insure the pointer assuming a definite position with each change in current value.

Ques. What are the characteristics of hot wire instruments?

Ans. Volt meters of this type are not affected by magnetic fields, and as their self-induction is small, they can be used on either direct or alternating currents; but they possess certain serious defects: they consume more current than the other types; cannot be constructed for small readings; are liable to burn out on accidental overloads; are somewhat vague in the readings near the zero point and are sometimes inaccurate in the upper part of the scale.

Ques. Describe the construction and operation of the Whitney hot wire instruments.

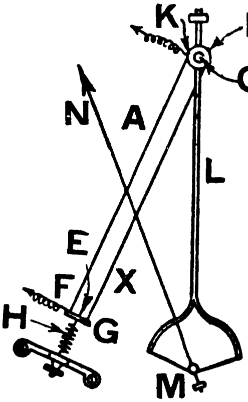


FIG. 1,353 —Diagram showing principle and construction of the Whitney hot wire instruments. The action of instruments of this type depends on the heating of a wire by the passage of a current causing the wire to lengthen This elongation is magnified by suitable mechanism and transmitted to the pointer of the instrument.

Ans. As shown in fig. 1,353, a wire AX, of non-oxidizable metal, of high resistance and low temperature coefficient, passes over a pulley B, mounted on the shaft C. The ends of the wire are attached to the plate E, at its ends F and G, the wire being insulated from the plate at G. A spring H, holds the wire in tension and takes up the slack due to the expansion caused by the heating of the wire when a current passes through it. The current flows only in the portion of the wire marked A, between the plate E, and the pulley B, up to the point K, where the connection is shown. When a current flows through the wire A, the spring takes up the slack, pulls A, around B, and causes B, to rotate upon its shaft C. It is clear, that a pointer attached to C, would indicate on a scale the movement of B, and C, but as this movement is very slight, a magnifying device will be required. This device consists of a forked rod L, rigidly attached to the shaft C, and carrying at its lower end a silk fibre fastened to the fork and passing around a pulley M, to which a pointer N, is attached. For direct current measurements only an electromagnetic system is used.

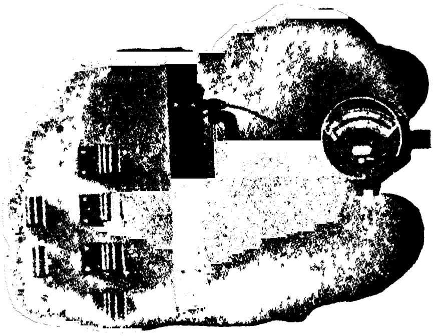


FIG. 1,354.—Weston swinging bracket, round pattern instrument.

Ques. What is the principle of electrostatic instruments?

Ans. The action of these instruments depends upon the fact that two conductors attract one another when any difference of electric pressure exists between them. If one be delicately suspended so as to be free to move, it will approach the other.

Ques. Describe the Kelvin electrostatic volt meter.

Ans. A simple form consists, as shown in fig. 1,355, of a metal case containing a pair of highly insulated plates, between which a delicately mounted paddle shaped needle is free to move.

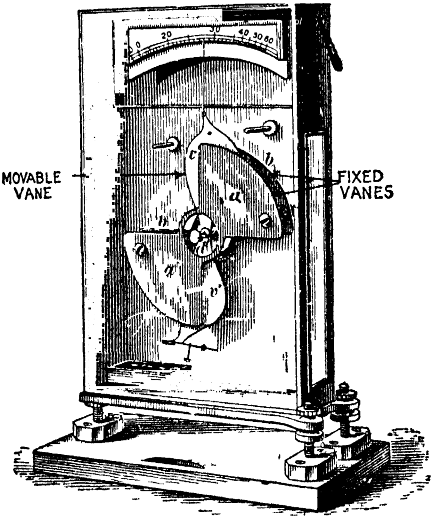
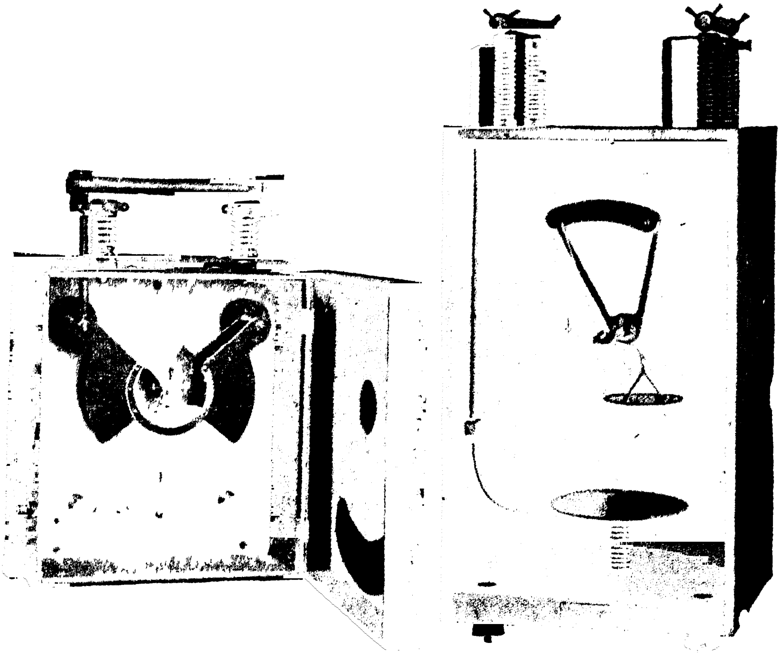


FIG. 1,355.—Kelvin electrostatic volt meter, a form of instrument designed for measuring high pressures up to 200,000 volts. The instrument, as illustrated, consists of fixed and movable vanes with terminals connecting with each. These vanes which act as condensers take charges proportional to the voltage difference between them, resulting in a certain attraction which tends to rotate the movable disc against the restraining force of gravity. In the figure *aa* and *b* are two fixed vanes and *c*, a movable vane, carrying a pointer and having a proper weight at its lower end.

When the needle is connected to one side of a circuit and the stationary plates to the other side, the needle is attracted and moves between them as indicated by the pointer. Adjusting screws at the lower end of the needle allow it to be balanced so that its center of gravity is somewhat below the center of suspension. Gravity then is the restraining force.

The range of the instrument may be changed by hanging different weights upon the needle By increasing the number of blades the instrument can be made to measure as low as 30 volts. The form having



Figs. 1,356 and 1,357.—General Electric electrostatic volt meters. Fig. 1,356, vane type, fig. 1,357, pan type. The main use of electrostatic volt meters is for measurement of voltages from 3 to 50 *kv*. For high voltages, the electrostatic volt meter has the advantage of being easily insulated, and as there is not a complete metallic circuit, it is not necessary to include in the construction a large amount of expensive resistance wire. In addition, instruments of this type draw an inappreciable current from the line which is of advantage in many cases. Electrostatic volt meters are used for cable testing and instrument testing where a ready determination of differences of pressure may be made and where a deviation from the correct value of ± 2.5 per cent is not objectionable. For best results, an electrostatic volt meter should be calibrated after it has been assembled and mounted. Resistances in series with the meter terminals are furnished to protect the instrument in the event of over-voltage on the circuit to which the volt meter is connected. Should an arc-over occur it would not greatly damage the instrument.

two stationary blades and one movable blade is suitable for measuring from 200 to 20,000 volts. The quadrant electrometer or laboratory form will measure a fraction of a volt.

Ques. Explain the construction and principle of the Thomson astatic instruments.

Ans. The fields of these instruments are electromagnets wound for any specified voltage and provided with binding posts separate from the current posts of the instrument. The moving coils are mounted upon an aluminum disc and are located in a magnetic field which is parallel to the shaft and astatically arranged. Two small pieces of magnetic metal are rigidly mounted on the shaft and the astatic components of the

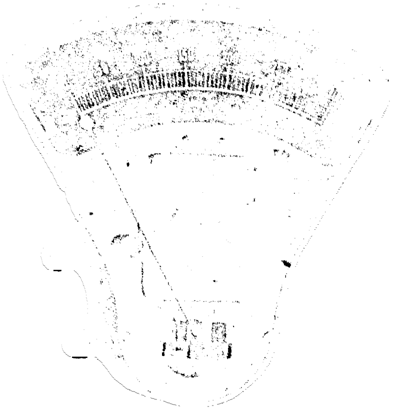
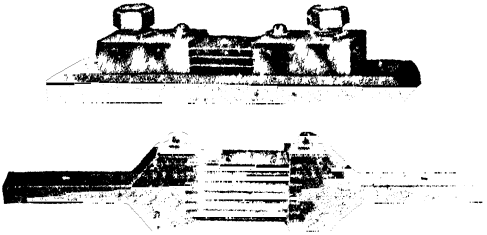


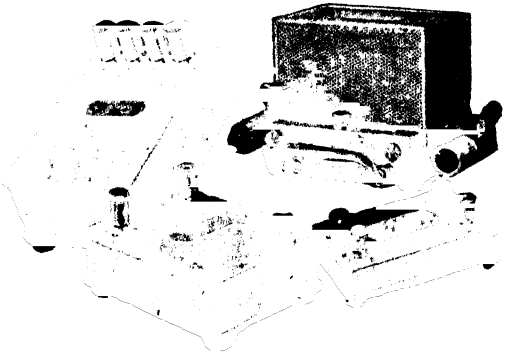
FIG. 1,358.—Thomson astatic instrument without cover. When current passes through the coils of the moving element, the lines of force parallel to the shaft produce a torque which tends to turn the shaft and cause the needle to travel across the scale. This action is, of course, opposed by the magnetic field at right angles to the shaft acting on the two pieces of magnetic metal. These astatic instruments have no controlling springs. The two small silver spirals which conduct the current to and from the armature are made of untempered silver and exert no force as springs. The actuating and restraining forces are dependent upon the same electro-magnets. The damping effect in these instruments is produced by an aluminum disc moving in a magnetic field, and is proportional to the square of the magnet strength.

magnetic field, which are perpendicular to the shaft, tend to keep the pieces of magnetic metal in their initial positions. When current passes through the coils of the moving element,



Figs 1,359 and 1,360 —Westinghouse shunts for ammeters Direct current ammeters for switchboard service are seldom made for capacities greater than 25 amperes For higher capacities external shunts are used with milli volt meters The milli volt meters are adjusted so that with 50 milli volts applied to the end of the instrument leads, the instrument will give full scale deflection, the scales being marked in amperes

Figs 1,361 to 1,369 —Weston switchboard shunts Each shunt consists of one or more sheets of a special alloy, fitted at each end into grooves in two copper blocks, which are provided with means for connecting the shunts in circuit with the main conductor and with the instrument In shunts up to and including a capacity of 2,500 amperes the terminal blades are an integral part of the shunt terminal Above this capacity the connecting terminal blades are copper, soldered and riveted into the shunt blocks the lines of force parallel to the shaft produce a torque which tends to turn the shaft and cause the needle to travel across the scale. This action is, of course, opposed by the magnetic field at right angles to the shaft acting on the two pieces of magnetic metal. There are thus no restraining springs, current being conveyed to the moving coil by torsionless spirals of silver wire. Thomson astatic instruments can be provided with polarity indicators, a red disc showing on the scale card where the poles are reversed. The effect of external fields is eliminated by the astatic arrangement of the fields and the moving parts. A field which tends to increase the torque on one side of the armature diminishes it to a corresponding degree on the other side. The damping effect in these instruments is produced by an aluminum disc moving in a magnetic field.



Figs. 1,370 to 1,373.—Weston standard portable shunts. The milli-volt meters used in connection with these shunts read directly in amperes. Shunts of different capacities can be adjusted to the same instrument, and it can, therefore, be used to measure a current of 2,000 amperes with the same degree of accuracy as a current of 1 ampere. In selecting shunts of different capacities for use in connection with one instrument it should be considered that the higher ranges must be even multiples of the lower one in order to suit the same scale on the instrument.

Ques. What are multipliers?

Ans. These are extra resistance coils which are connected in series with a volt meter for increasing its capacity or readings. They are put up in portable boxes, and must be adjusted for each particular volt meter as the resistance of a multiplier coil must be a multiple of the resistance of the volt meter itself.

Ques. What is an electro-dynamometer?

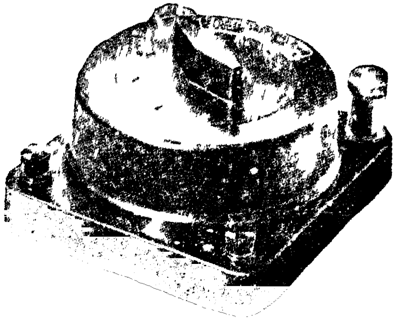


FIG 1,374 —Weston rotary switch type multiple range portable precision shunt These are seven range series type precision shunts, constructed so that any range may be selected at will, by merely turning the switch handle until the index shows the desired range to be in circuit It is not necessary to open either the main or the instrument circuit when changing the range By turning one notch above the highest range, the entire shunt is short circuited.

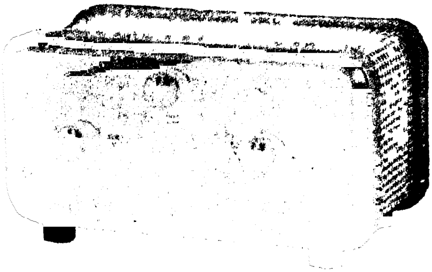
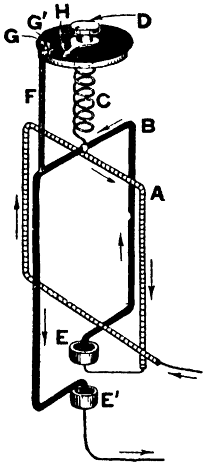


FIG. 1,375 —Weston multiplier for standard ammeter These multipliers are resistors having a definite multiplying constant, the resistance material of which is highly insulated and arranged for proper heat dissipation They are so adjusted that the readings of the instrument may be multiplied by a specific constant Multipliers are usually constructed so that the indication of the pointer, multiplied by 2, 5, 10 or 20 will give the voltage of the circuit.

Ans. An instrument for measuring amperes, volts, or watts by the reaction between two coils when the current to be measured is passed through them. One of the coils is fixed and the other movable.

Ques. Describe the Siemens' electro-dynamometer.



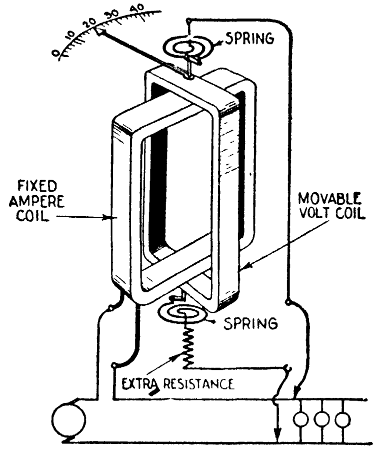


Fig. 1,376.—Diagram of Siemens' electro-dynamometer. ***It consists of*** two coils on a common axis, but set in planes at right angles to each other in such a way that a torque is produced between the two coils which measures the product of their currents. This torque is balanced by twisting a spiral spring through a measured angle of such degree that the coils shall resume their original relative positions. If the instrument be used for measuring ***current,*** the coils are connected in series, and the reading is then proportional to the square of the current. If used as a ***watt meter,*** one coil carries the main current and the other a small current, which is proportional to the pressure. The reading is then proportional to the power in the circuit.

Fig. 1,377.—Diagram showing connections of Siemens' electro-dynamometer as arranged to read watts.

Ans. The essential parts are shown in fig. 1,376. The fixed coil A, composed of a number of turns of wire is fastened to a vertical support, and surrounded by a movable coil B of a few turns, or often of only one turn. The movable coil is suspended by a thread and a spiral spring C, below the dials which are fastened at one end to the movable coil and at the other end to a milled headed screw D, which can be turned so as to place the planes of the coil at right angles to each other, and to apply torsion to the spring to oppose the deflection of the movable coil for this position when a current is passed through the coils. The ends of the movable coil dip into two cups of mercury E, E′, located one above the other and along the axis of the coils so as to bring the two in series when connected to an external circuit.

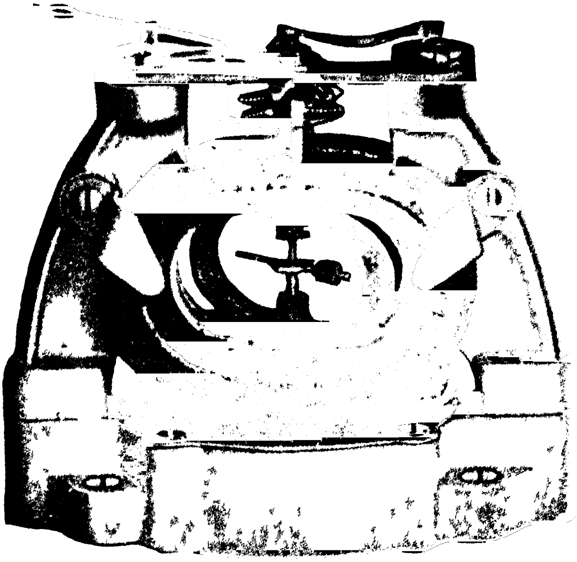
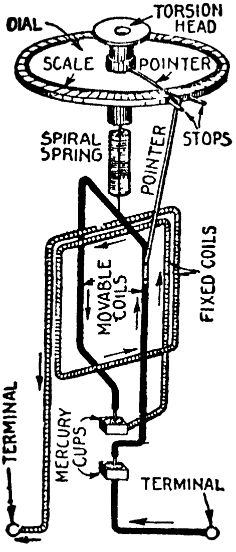


FIG 1,378 —Roller-Smith electro-dynamometer used in watt meters.

The arrows show the direction of current through the two coils An index pointer F, is attached to the movable coil The upper end of this pointer is bent at a right angle, so that it swings over the dial between two stop pins G,G′, and rests directly over the zero line when the planes of the coils are at right angles to each other. A pointer H, is attached to the torsion screw D, and sweeps over the scale of the dial. The spring is the controlling factor in making the measurement.



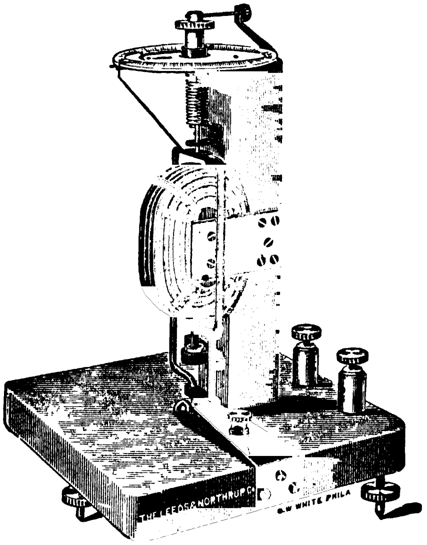


Fig. 1,379.—Diagram of Siemens' dynamometer with names of parts. *When constructed as a volt meter,* both coils are wound with a large number of turns of fine wire, making the instrument sensitive to small currents. Then by connecting a high resistance in series with the instrument, it can be connected across the terminals of a circuit whose voltage is to be measured. *When constructed as a watt-meter,* one coil is wound so as to carry the main current and the other made with many turns of fine wire of high resistance suitable for connecting across the circuit

Fig. 1,380.—Leeds and Northrup *electro-dynamometer. It is a reliable instrument for the measurement of alternating currents of commercial frequencies.*

Ques. Explain the operation of the Siemens' electrodynamometer.

Ans. In fig. 1,376, when a current is passed through both coils, the movable coil is deflected against a stop pin, then the screw D, is turned in a direction to oppose the action of the current until the deflection has been overcome and the coil brought back to its original position. The angle through which the pointer of the torsion screw was turned is directly proportional to the square root of the angle of the torsion. To determine the current strength in amperes, the square root of the angle of torsion is multiplied by a calculated constant furnished by the makers of this instrument.

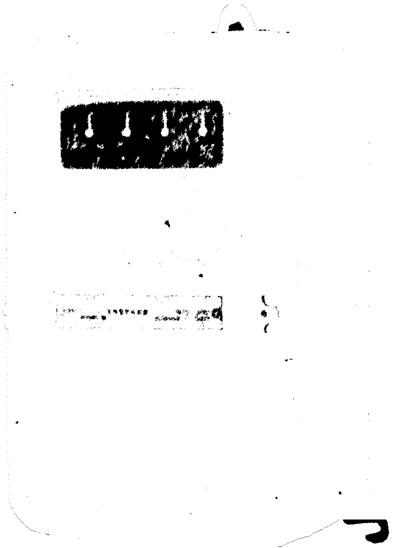


Fig 1,381.—General Electric, Thomson type C-6 direct current watt hour meter. It is standard practice to furnish flexible cable leads provided with copper terminals for meters of 100 amperes capacity and above. For meters of lower capacity, the leading-in wires are fastened to suitable brass binding posts with set screws

Ques. How is the electro-dynamometer adapted to measure volts or watts?

Ans. Both coils are wound with a large number of turns of fine wire making the instrument sensitive to small currents.

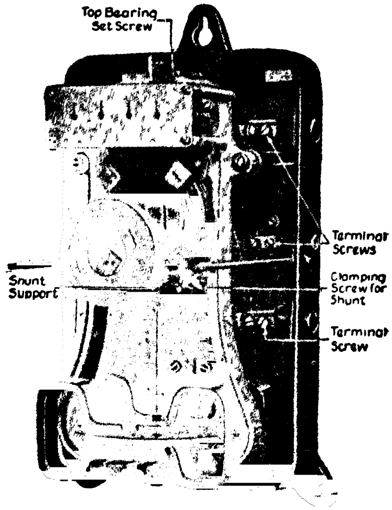


FIG. 1,382.—General Electric, Thomson type C-6 direct current watt hour meter with cover removed.

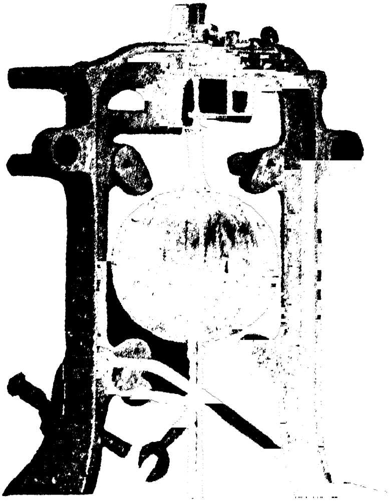
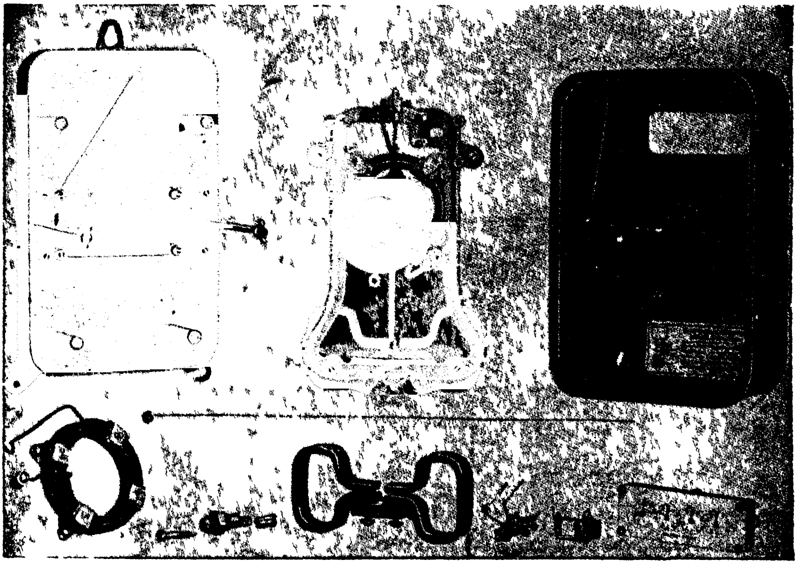


FIG. 1,383.—Interior of General Electric Thomson type watt hour meter (type C-6) showing

Then by connecting a high resistance in series with the instrument it can be connected across the terminals of a circuit whose voltage is to be measured.

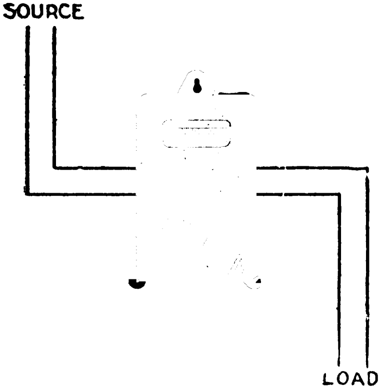
When constructed as a watt meter, one coil is wound so as to carry the main current, and the other made with many turns of fine wire of high resistance suitable for connecting across the circuit. With this arrangement, the force between the two coils will be proportional to the product of amperes by volts, hence, the instrument will measure watts.



Figs 1,384 to 1,394.—Parts of type C-6 Thomson watt hour meter.

Fig 1 383 —*Text continued*

armature, small commutator and gravity brushes A spherical armature moving within circular field coils is the construction adopted in this meter The armature is wound on a very thin paper shell, stiff enough to withstand the strain due to winding and subsequent handling The wire composing the armature is of the smallest gauge consistent with mechanical strength The field coils, as before stated, are circular, and are placed as near each other as possible, one on either side of the armature, with the internal diameter just sufficient to give the necessary clearance for the rotating element This construction prevents magnetic leakage Ribbon wire is employed for the field coils, thus economizing space and further carrying out the idea of concentration



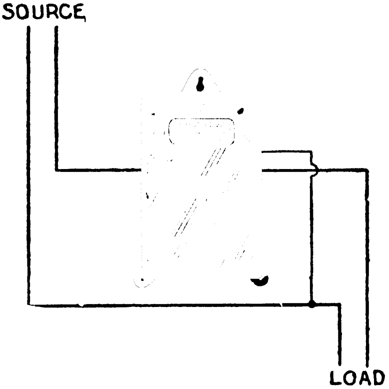
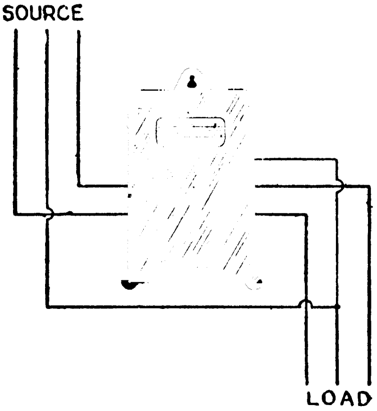


Fig. 1,395.—General Electric type C-6 *d. c.* watt hour meter, two wire connections, 5 to 50 amperes up to 240 volts; type C-7, 5 to 25 amperes, 500 to 600 volts.

Fig. 1,396.—General Electric type C-6 *d. c.* watt hour meter, two wire connections. 75 to 600 amperes up to 240 volts; 50 to 600 amperes, 500 to 600 volts.



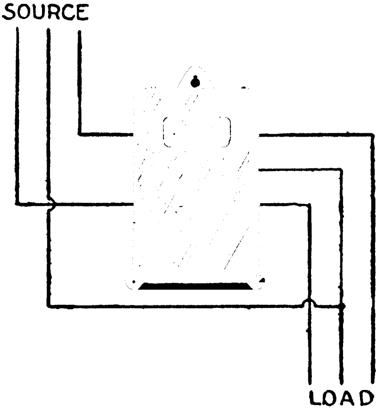


Fig. 1,397.—General Electric type C-6 *d. c* watt hour meter, three wire connections. 5 to 50 amperes, 200 to 240 volts.

Fig. 1,398.—General Electric type C-6 *d. c.* watt hour meter, three wire connections. 75 to 300 amperes, 200 to 240 volts.

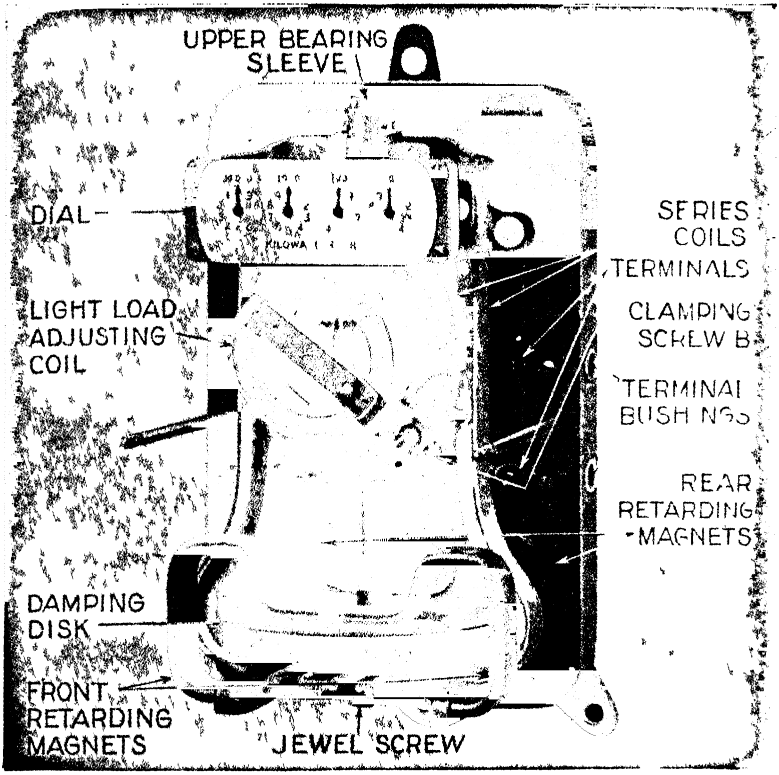


Fig 1 399 —Westinghouse type CW 6 watt hour meter with cover off This meter is of the commutator type without iron in the magnetic circuit The spherical armature is closely surrounded by circular field coils which provide the shortest magnetic path and smallest magnetic leakage thus securing high torque with small consumption of energy The armature winding is wound on a hollow sphere of prepared paper which is moulded in corrugated form to secure strength Uniform brush tension is maintained by gravity Each brush consists of two small round wires placed side by side and held against the commutator by a small counterweight whose distance from the fulcrum is adjustable The current winding consists of two flat coils of strap copper one clamped rigidly on either side of the central mounting frame which supports the armature bearings These coils are connected either in series or parallel depending on the capacity In three wire meters one of the coils is connected in series with each side of the line The retarding element consists of a light aluminum disc rotating between two pairs of permanent magnets The magnets are prepared by a special aging process to insure permanence Full load adjustment is made by shifting the

Ques. Describe briefly the construction of the Thomson recording watt meter.

Ans. It consists of four elements: 1, a motor causing rotation; 2, a dynamo providing the necessary load or drag; 3, a registering device, the function of which is to integrate the instantaneous values of the electrical energy to be measured, and 4, means of regulation for light and full load.

Ques. What is the action of the motor in the Thomson watt hour meter?

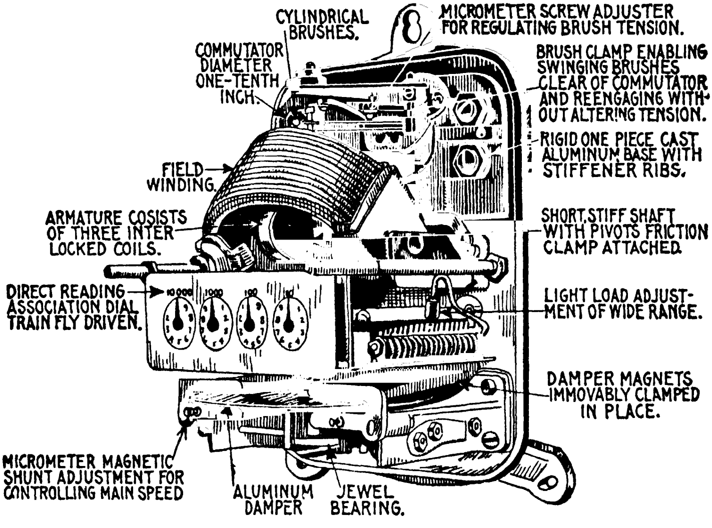

CYLINDRICAL BRUSHES.
MICROMETER SCREW ADJUSTER FOR REGULATING BRUSH TENSION.
COMMUTATOR DIAMETER ONE-TENTH INCH.
BRUSH CLAMP ENABLING SWINGING BRUSHES CLEAR OF COMMUTATOR AND REENGAGING WITHOUT ALTERING TENSION.
RIGID ONE PIECE CAST ALUMINUM BASE WITH STIFFENER RIBS.
FIELD WINDING.
ARMATURE COSISTS OF THREE INTER LOCKED COILS.
SHORT, STIFF SHAFT WITH PIVOTS FRICTION CLAMP ATTACHED.
DIRECT READING ASSOCIATION DIAL TRAIN FLY DRIVEN.
10000
1000
100
LIGHT LOAD ADJUSTMENT OF WIDE RANGE.
DAMPER MAGNETS IMMOVABLY CLAMPED IN PLACE.
MICROMETER MAGNETIC SHUNT ADJUSTMENT FOR CONTROLLING MAIN SPEED
ALUMINUM DAMPER
JEWEL BEARING.

FIG. 1,400 —Interior view of Columbia watt hour meter (type D), showing construction and principal parts and connections.

FIG. 1,399 —*Text continued.*

position of the permanent magnets. Ample light load adjustment or friction compensation is provided by means of the movable coil, which can be shifted horizontally or radially on loosening one screw. The meter registers directly in kilowatt hours.

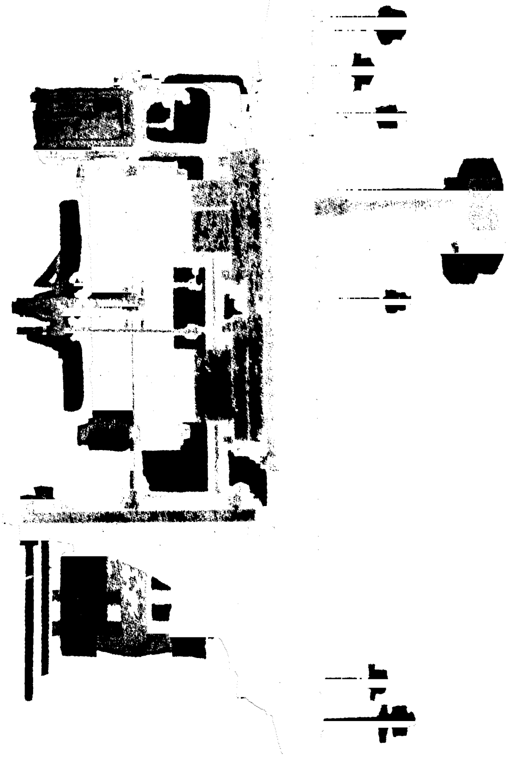


FIG 1,401 —General Electric, Thomson type CS astatic watt hour meter with cover and magnet shield removed This meter is constructed on the astatic principle to minimize the effect of external magnetic fields which are commonly encountered when dealing with large direct current circuits These fields may be due to several causes such as an adjacent bus bar carrying large currents, iron frame work of switchboards, steel girders in buildings, etc, and they would naturally tend to affect the registration of the meter by an amount dependent on the direction of the external field and the ratio its strength bears to that of the meter field The astatic principle which is the important feature of these meters, involves the use of two motor elements Obviously, if one field coil and its armature be considered, a projected field from an adjacent bus bar or similar source of disturbance would tend to alter the field within the series coil, and its effect on the registration of the meter would be proportional to the strength and direction of this stray field Now, by combining with this element another field coil and armature identical with the first, except as regards polarity which is just the opposite of the other element, the effect of the stray field becomes neutralized, that is, a projected field from any external source tending to strengthen one field would in general weaken the other by the same amount, the net result representing no change in torque.

Ans. It rotates at very slow speed, and since there is no iron in its fields and armature, it has very little reverse voltage. Its armature current, therefore, is independent of the speed of rotation, and is constant for any definite voltage applied at its terminals.

The torque of this motor being proportional to the product of its armature and field currents, must vary directly as the energy passing through its coils In order then that the motor shall record correctly, it is necessary only to provide some means for making the speed proportional to the torque This is accomplished by applying a load or drag, the strength of which varies directly as the speed

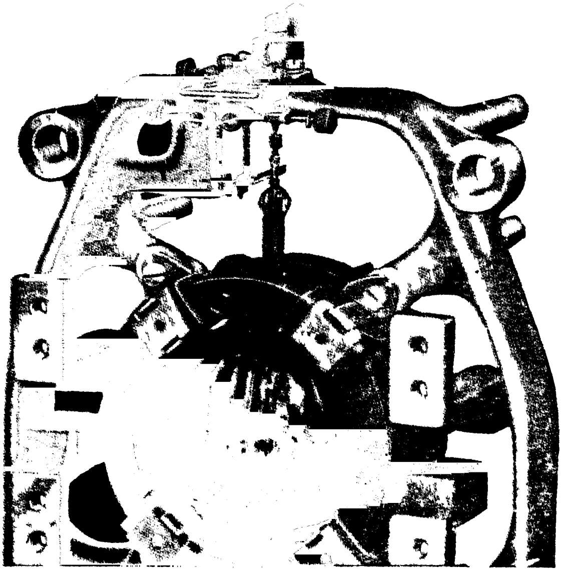
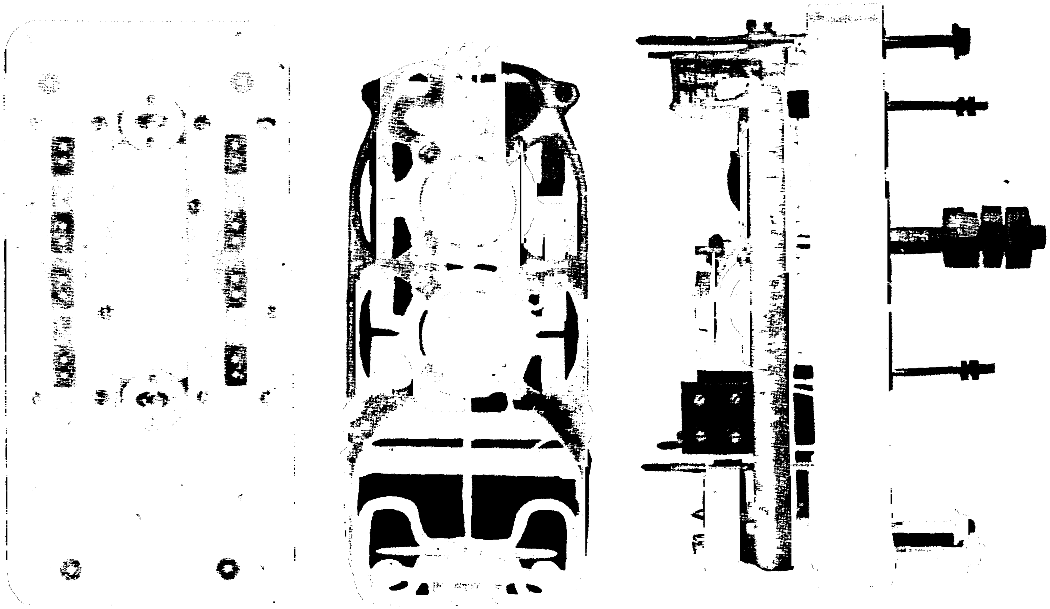


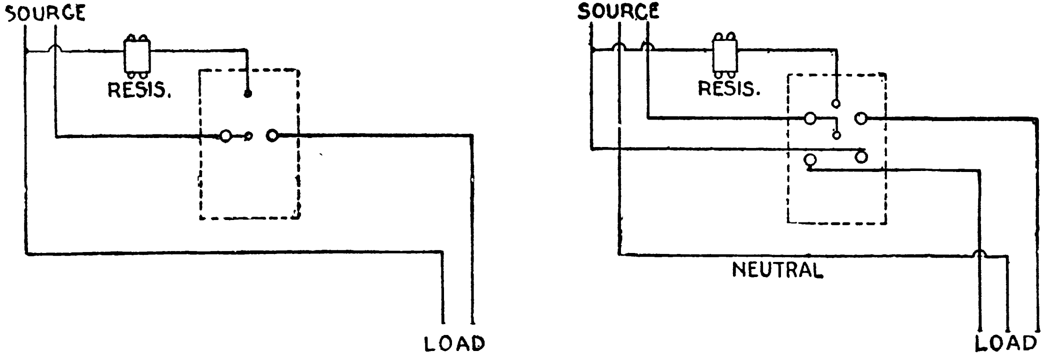
Fig 1,402 —Detail of brush construction and arrangement of Thomson astatic watt hour meter

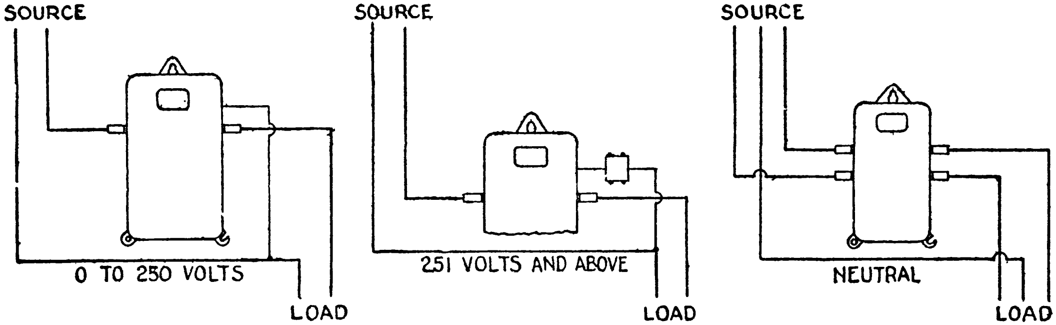
Ques. Explain the operation of the Thomson recording watt meter.



Figs. 1,403 to 1,405 —Thomson astatic watt hour meter back connection for switchboard mounting. Fig. 1,403, base and terminals, fig. 1,404, frame and electrical element; fig. 1,405, side view.

Ans. There being no iron in either field or armature of the motor element, no considerations of saturation are involved. The torque or pull of the armature is dependent upon the product of the field and armature strength. The strength of the





Figs. 1,406 and 1,407.—External connections of Thomson watt hour meters. type CS two and three wire, 50 to 1,500 amperes with external resistor.

Figs. 1,408 to 1,410.—Connections of Thomson watt hour meter, type CS 3, 15 to 600 amperes two wire, 15 to 400 amperes, three wire.

field, there being no iron, varies directly with the current in the field. Thus the strength of the field with 10 amperes flowing to the load is exactly twice the strength of the field with 5 amperes flowing to the load.

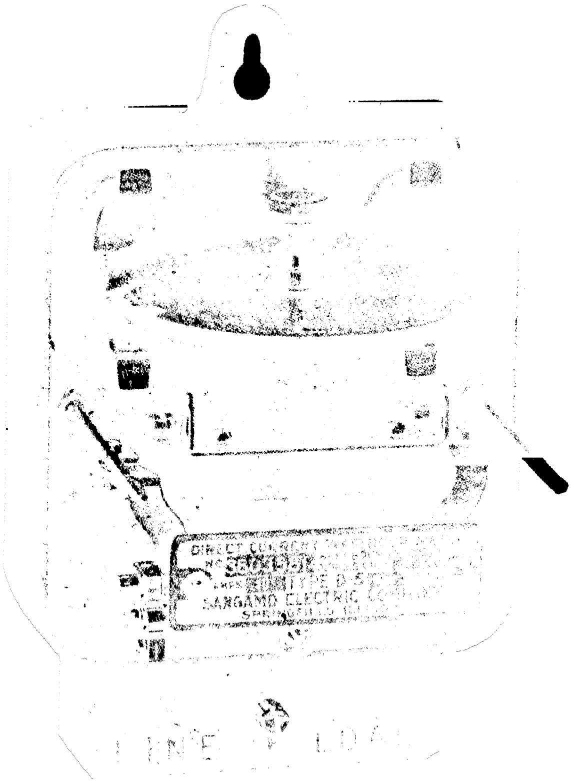


FIG. 1,411.—Sangamo service type two wire, direct current watt hour meter, with cover and recording train removed. *It consists of* a motor dynamo set coupled to a revolution recording mechanism, the speed of the set being proportional to the power delivered through it. The mercury motor consists essentially of a copper disc floated in mercury between the poles of a magnet and provided with leads to and from the mercury at diametrically opposite points.

The strength of the armature is dependent on the voltage of the system to which it is connected, the armature element of the meter being practically a volt meter. There is, therefore, a torque or pull varying directly with the strength of the armature multiplied by the strength of the field, or, in other words, varying directly with the watt load, and except in so far as influenced by friction, the speed of rotation varies directly with the torque or pull. The currents generated in the disc armature consist of eddy currents, which circulate within the mass of the disc.

Installation of Watt Meters.—The various types of watt meter differ so widely either in mechanical details, or operating principles, that it is customary for manufacturers to furnish detailed instructions for the installation of their meters. Such instructions should be carefully followed in all cases, but the following will be found generally applicable to all types of motor meter:

1. After unpacking the meter, and before opening the case or cover,

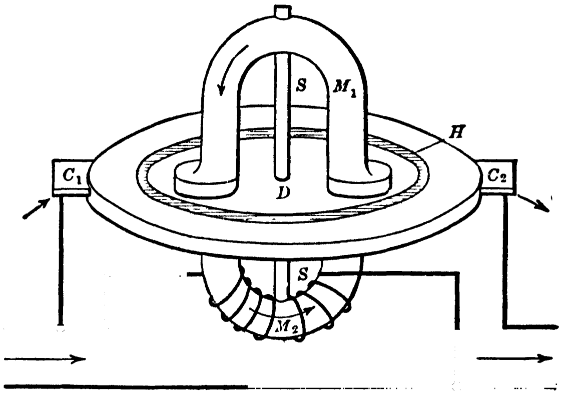


FIG. 1,412.—Electric and magnetic circuits of the mercury motor of Sangamo D-5 watt hour meter. The current of electricity, carried by the circuit in which energy is to be measured, enters the contact C , passes through the comparatively high resistance mercury H, to the edge of the low resistance copper disc D, across through the disc to the mercury H, and out of the contact C_2. The magnetic field of the motor is excited by a winding connected across the circuit, in which energy is to be measured; that is, the magnetic field is proportional to the voltage.

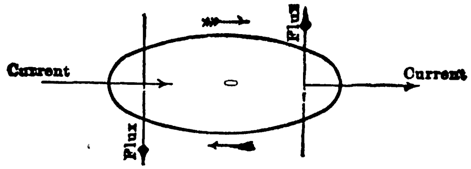
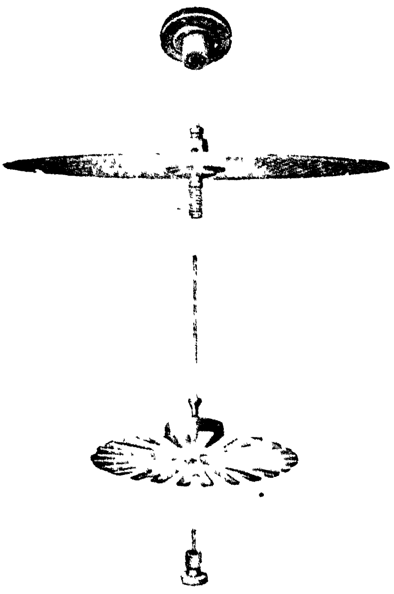
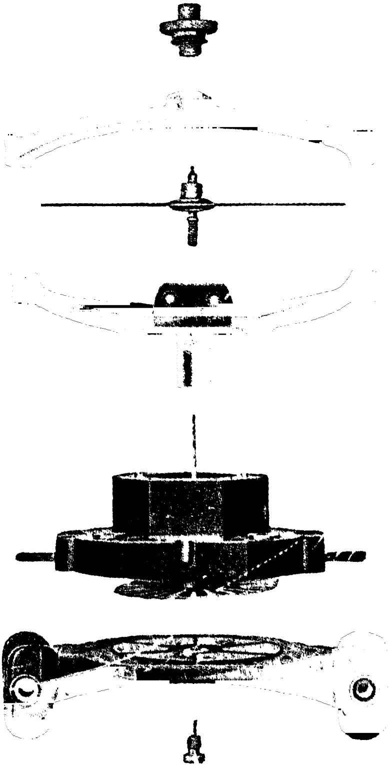


FIG. 1,413.—Relative directions of current, magnetic flux and rotation of disc of Sangamo D-5 watt hour meter.

clean the latter carefully to remove all adhering particles of dust and excelsior.

2. The proper location for the meter should be one where there is no vibration. When this location has been selected, nail or screw upon the walls, a board somewhat larger than the dimensions of the back of the meter, and upon this board hang the meter by the top hanger,





Figs. 1,414 to 1,417.—Disassembled moving system of Sangamo two wire, direct current watt hour meter.

Figs. 1,418 to 1,424.—Field magnet, mercury chamber, main bracket and moving parts of Sangamo two wire, direct current watt hour meter.

3. After hanging the meter, open or remove the case or cover, and if necessary, put the mechanism in order according to instructions furnished by the manufacturer.
4. In order to operate satisfactorily, the meter should hang plumb, so that the spindle of the revolving element will be vertical, and the horizontal planes through the armature and retarding disc will be level. Many complaints relative to meters being slow on light loads, are invariably due to the fact that the meters have been installed out of plumb.*
5. In making the circuit connections, be very careful that the *positive* lead or wire is placed in the *positive* binding post of the meter. This precaution is essential for insuring an accurate and sensitive measurement on small loads.

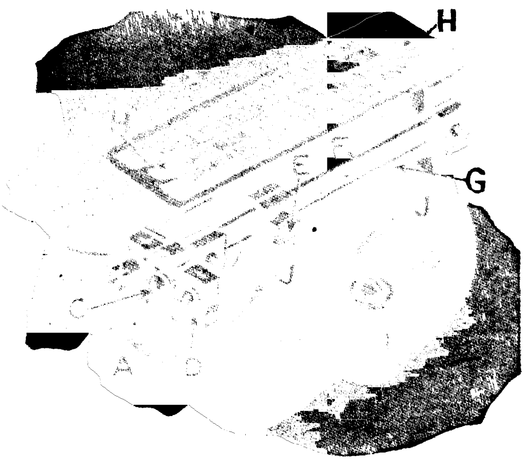


FIG. 1,425.—Thermo-couple and light-load adjustment of Sangamo direct current watt hour meter. A, is the thermo-couple winding which encloses a couple consisting of two strips of dissimilar metal, each end terminating in a slotted terminal held by screws B and C. As shown, the couple is connected for use on the positive side of the line; loosening the screws and moving it to connect across C and D, adapts it for use on the negative side of the line. The light load adjustment is obtained by moving the clamp E, one way or another along the resistance strip. The round wire is of copper, while the flat strip is of resistance metal.

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*NOTE.— ***The most practical*** and accurate method of plumbing a meter is to level it by means of a small brass weight placed upon the retarding disc. Place the weight upon the front or back upper surface of the disc, close to the edge. If the disc and weight rotate toward the right, move the bottom of the meter in the same direction so as to raise the disc on the right. When the disc is level, the weight and disc will remain stationary when the weight is placed on either the front or the back of the disc. Next, place the weight on the disc close to the edge on either side. If the disc rotate toward the front, swing the bottom of the meter away from the wall or board until the disc remains stationary when the weight is placed upon it on either side. If the disc rotate toward the back, raise it up on that side by bringing the top of the meter away from the wall or board. It is possible that the second leveling operation will alter the position of the disc obtained by the first operation, therefore, the first should be repeated, and after that the second also, until the disc remains stationary when the weight is placed at any point upon its surface. This method of leveling is more reliable than any method in which a spirit level is employed.

6. When a meter of the commutator motor type sparks at the brushes at starting, it is an indication that the commutator is dusty. Clean it with a piece of closely woven cotton tape ¼ in. in width.

7. Meters should never be allowed to remain with their covers off, in the testing room station, or any other place. In order to get the best service, and to give them long life they must be kept clean.

NOTE —Sangamo meters for use on circuits of more than 130 volts are provided with resistors connected in series with the voltage magnet windings, and these resistors, when used in meters for circuits not exceeding 250 volts, are mounted upon and form a part of the motor element. On circuits of more than 250 volts the series resistor is mounted in an external box.

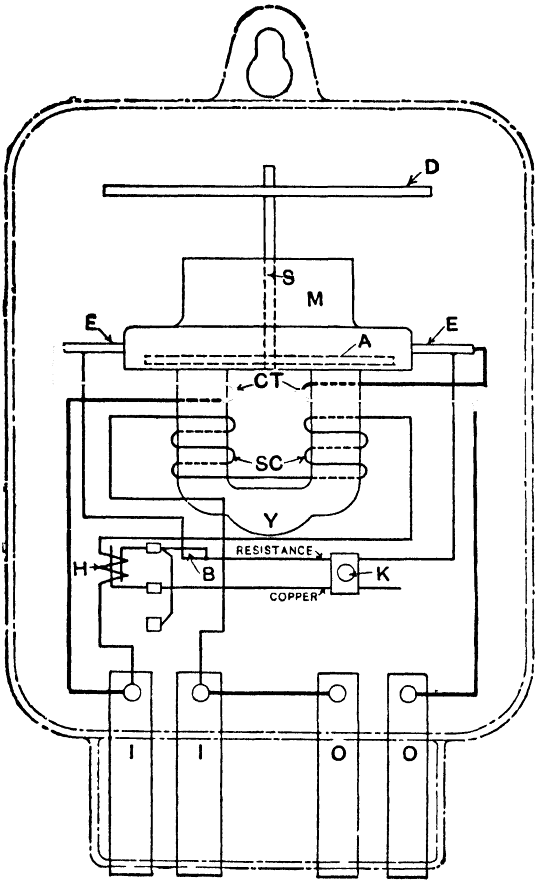

Fig. 1,426.—Internal circuits of Sangamo two wire direct current watt hour meter.* ***Elements in two and three wire meters:*** **A**, armature, **B**, zero point of light load adjustment **D**, damping disc, **E,E**, contact ears of mercury chamber; **H**, heater winding of thermo couple, **I,I**, binding post "from line." **K**, clamp slider of light load adjustment; **M**, motor element; **N**, adjustment for drop of shunt; **O,O**, binding posts "to load," **S**, spindle; **U**, upper bearing; **W**, worm driving recording train; **Y**, laminated shunt magnet, **SC**, shunt coils; **CT**, compounding turns to build up speed on heavy loads.

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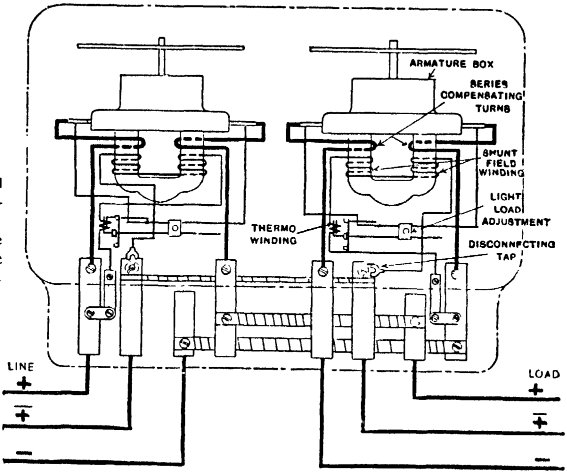
*NOTE.—The reference letters under fig. 1,426 apply to figs. 1,426 and 1,428.

Fig. 1,427 — Internal connections of the unshunted and internally shunted Sangamo type D-5 three wire service type watt hour meter.



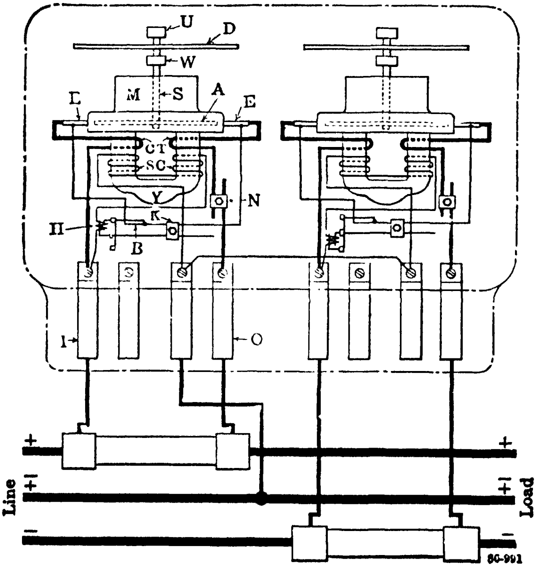
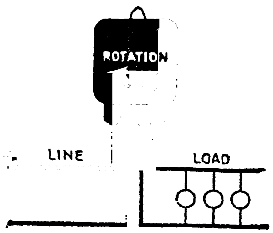
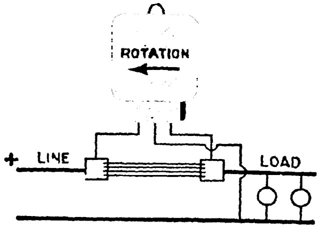


Fig. 1,428. — Internal connections of the externally shunted Sangamo type D-5 three wire service type watt hour meter.





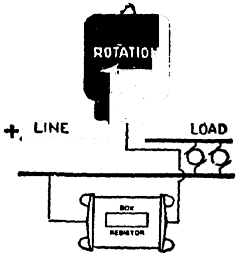
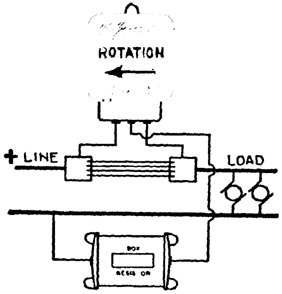
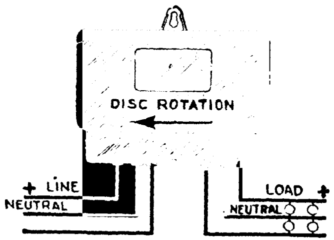


FIG 1 429 —Sangamo two wire meter for circuits up to 250 volts, capacities 10 to 75 amperes inclusive

FIG 1,430 —Sangamo two wire meter for circuits up to 250 volts, capacities 100 amperes and over, with external shunt

FIG 1,431 —Sangamo two wire meter for circuits above 250 volts, capacities 10 to 75 amperes inclusive, with external box resistor





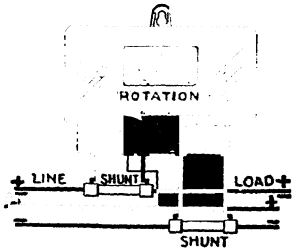
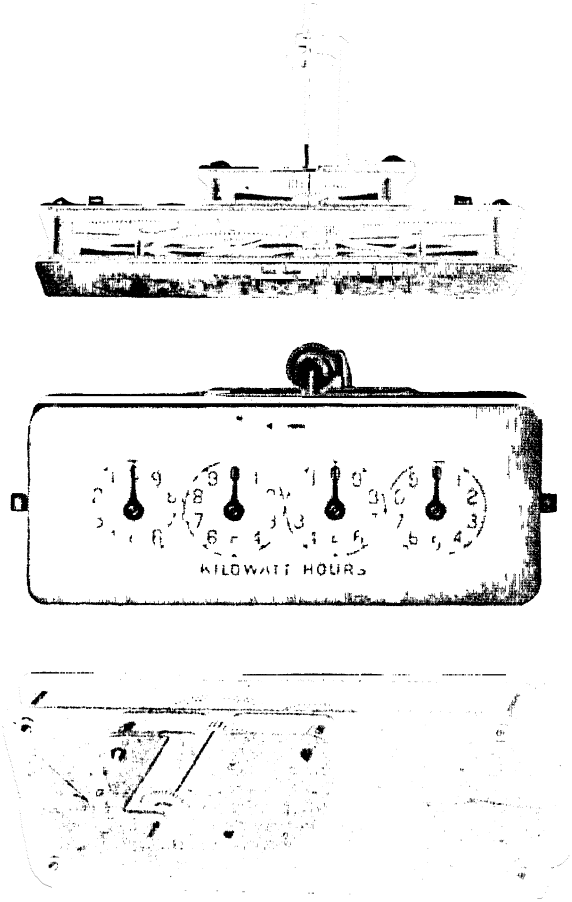


FIG 1,432 —Sangamo two wire meter for circuits above 250 volts, capacities 100 amperes with external box resistor and external shunt.

FIG. 1,433 —Sangamo three wire meter, unshunted and internally shunted.

FIG. 1.434 —Sangamo three wire meter 110-220 volts, capacities 100 amperes and over, with external shunts.

How to Test a Meter.—A simple test for ascertaining whether a customer's meter is fast or slow, may be applied as follows:



FIGS. 1,435 to 1,437.—Three views of recording mechanism of Sangamo two wire watt hour meter

1. Turn off the lamps and other power consuming devices in the house and then note the reading of the meter dial and the exact time of day,

2 Turn on as quickly as possible about one-tenth of all the lamps in the house and allow them to burn for about two hours;

3. At the end of two hours, turn off the lamps as quickly as possible and note the reading of the meter dial.

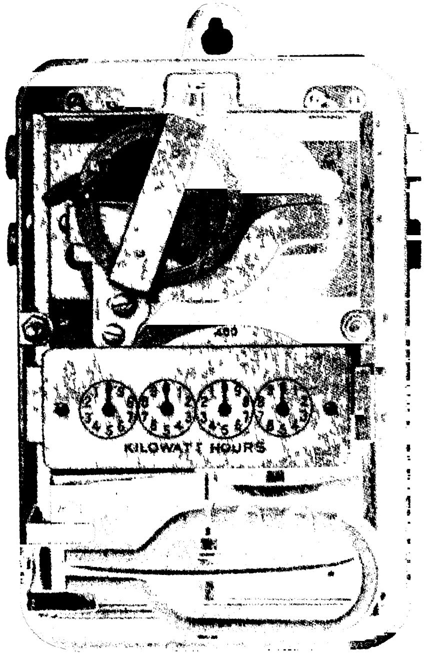


Fig. 1,438 —Duncan model EK, direct current watt hour meter.

The difference between the first and second readings of the dial will be the indicated consumption of two hours, and if this be greater than the amount of power that ought to be consumed by the number of lamps turned on, the meter is fast, but if it be less, the meter is slow.

The best results obtained by this method are only approximations, however, on account of the variations in the watts consumed by the different makes of lamp, the uncertainty as to the actual voltage on the line at the time of the test, and the lack of knowledge as to the age of

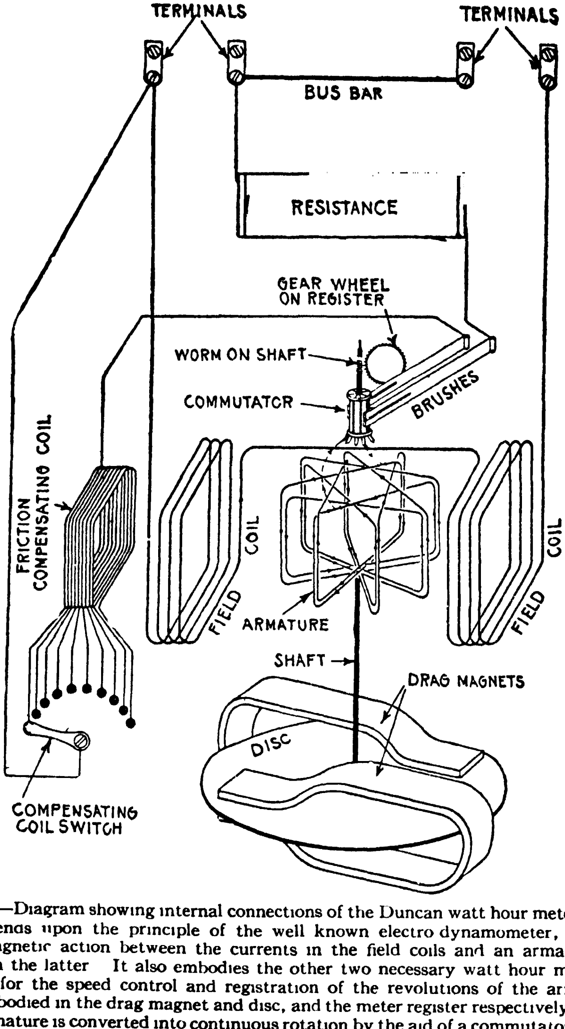
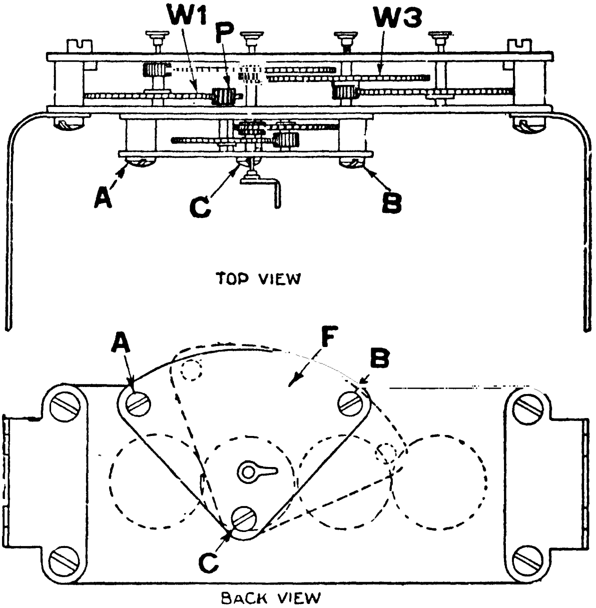


FIG. 1,439 —Diagram showing internal connections of the Duncan watt hour meter Its operation depends upon the principle of the well known electro dynamometer, in which the electromagnetic action between the currents in the field coils and an armature produces motion in the latter It also embodies the other two necessary watt hour meter elements required for the speed control and registration of the revolutions of the armature, these being embodied in the drag magnet and disc, and the meter register respectively The motion of the armature is converted into continuous rotation by the aid of a commutator and brushes, the commutator being connected to the armature coils and carried on the same spindle therewith.

the lamps. Therefore, if the meter test within five per cent., or do not record more nor less than one-twentieth of the assumed lamp consumption it is safe to assume that the meter is correct as the result of the test is not likely to be any closer to the truth.

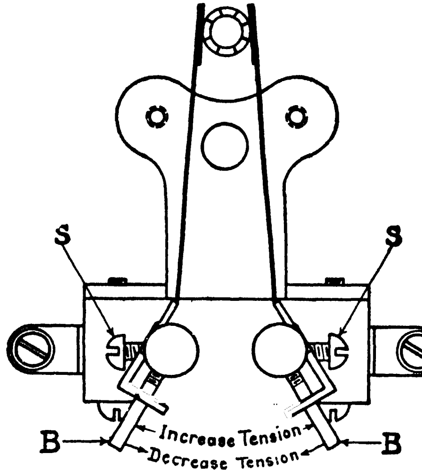


Figs. 1,440 and 1,441.—Duncan model E, register. ***Instructions for resetting register to zero:*** remove complete register from the meter; remove screws A an B; loosen screw C, one half of a turn; disengage pinion P, from gear wheel W1, by moving frame F, to the right as shown by dotted line; re-set the dial pointers by turning gear wheels W3 and W1; move frame F, back in place and replace screws A and B; adjust mesh of pinion P, and gear wheel W1, to allow slight backlash; tighten screws A, B and C.

Ques. How should a roughened commutator be cleaned and smoothed?

Ans. By means of tape.

Waste of Electricity in Lighting.—In large residences where a good many servants are employed or in any place where the



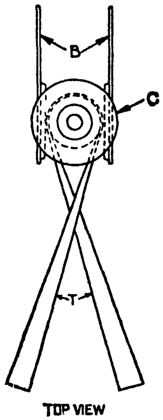
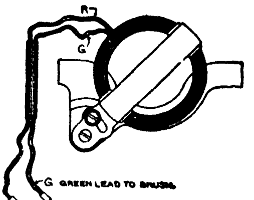
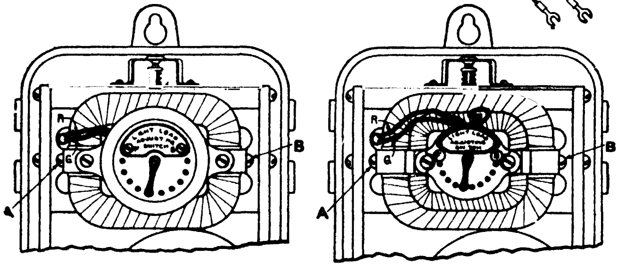


FIG. 1,442.—New style Duncan brushes. ***Method of adjustment:*** loosen set screw S, change tension by moving arm B, in the direction indicated, tighten set screw S.

FIG. 1,443 —Method of polishing Duncan commutator with tape.





FIGS 1,444 to 1,446 —Duncan meter showing method of replacing fixed type compensating coil with swinging type R, red lead to positive series binding post if 110 volt meter; if 220 volt meter, connect red lead to pan cake coil resistance on front of meter base. To replace fixed compensating coils and switches shown in figs 1,444 and 1,445 with the movable compensating coil, illustrated in fig. 1,446, disconnect green lead G, from brush; disconnect lead R, remove screws A and B, remove coil and switch as a unit, substitute movable coil, replace screws A and B; connect red and green leads as indicated.

power consumed is not directly under the supervision of the person who must pay the bills, a great deal of waste usually occurs.

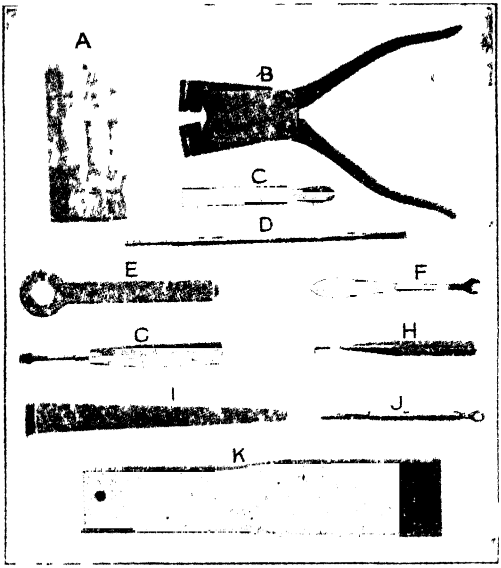


Fig. 1,447 to 1,457.—Tools for use with Duncan *d c* watt hour meters, both old and new types. A, sticks of corn pith, B, sealing tool, C, brush cleaner, D, brush adjuster, E, magnet wrench, F, brush wrench, G, armature screw driver, H, commutator pick, I, magnet cleaner (phosphor bronze), J, pivot remover, K, magnet adjuster.

NOTE.—***A meter*** operates under more varied and exacting conditions than almost any other piece of apparatus. It is frequently subjected to vibration, moisture and extremes of temperature, it must register accurately on varying voltages and various wave forms, it must operate for many months without any supervision or attention whatever, and, in spite of all these conditions, it is expected to register with accuracy from a few per cent of its rated capacity to a 50 per cent overload. As a meter is a type of mechanism, its natural tendency is to run slow; but occasionally, through accident, a meter may run fast. When a meter runs fast the consumer is paying a higher rate per kilowatt hour than his contract calls for. He is being discriminated against. The periodic testing of meters is therefore a necessity and is an indication of the honesty of intention of the manager toward the customers of his company. Meters controlling a very large amount of revenue may be tested as often as once a month, while the ordinary run of meters should be tested at least once a year, once in eighteen months or once in two years, the period varying with different companies, different types and different civic requirements. Commutator type meters, having comparatively heavy moving elements with consequent rapid increase in friction due to wear on the jewel and bearings, and a commutator also increasing in friction with age, must have frequent and expert attention to insure their accuracy under all conditions.

HOW TO READ A METER

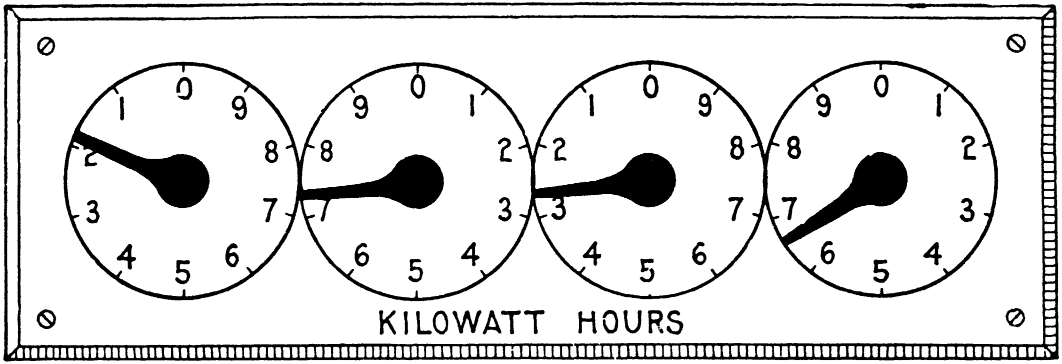


FIG 1,458 —Recording dials of watt hour meter, illustrating method of reading electric meters The unit of measurement of electrical energy is the watt hour 1,000 watt hours make or equal 1 kilowatt hour Some electric meters have 4 dials, the extreme right hand dial of which registers in kilowatt hours while others have 5 dials, the extreme right hand dial of which registers in tenths of kilowatt hours In making out bills to customers the extreme right hand dial of a 5 dial meter is ignored in order that the "state of meter" shown on bills *uniformly* requires the addition of 3 ciphers to correctly express the registration in watt hours. Each division on the right hand dial (ignoring the 5th dial mentioned) denotes 1,000 watt hours or 1 kilowatt hour, on the next dial 10 kilowatt hours, on the next dial 100 kilowatt hours and on the left hand dial 1,000 kilowatt hours. One complete revolution of any dial causes the hand on the dial immediately to its left to move forward one division To take a statement from the meter begin at the left and set down for each dial the *lower* figure next to each hand, not necessarily the figure nearer the hand In the above example the statement is 1,726 kilowatt hours or 1 726 000 watt hours Subtract the previous statement to arrive at registration for a given period Some meters are subject to a multiplying constant so stated on their face and the registration of such meters must be multiplied by the constant as shown, to determine the actual consumption of electrical energy. The constant is the measure of the mechanical adjustment in the register of the meter and is the ratio between the registration of the dial hands and the true consumption. This adjustment is made always by the manufacturer of the meter and is never changed in service.

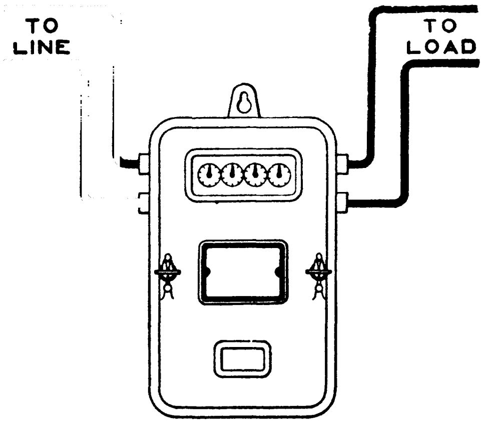


FIG 1 459 —Connections of Duncan model E two wire, 4 binding posts *d c* watt hour meter, 50 amperes and less, 550 volts and less

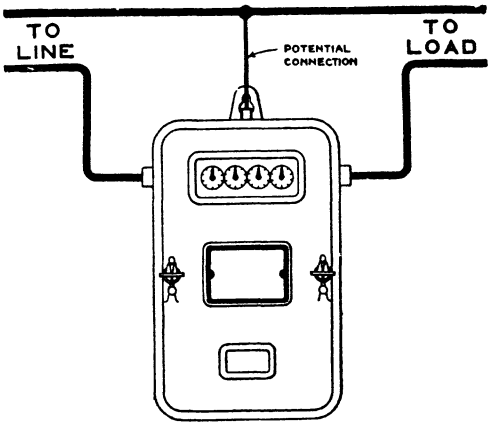


FIG 1,460 —Connections of Duncan model E two wire 3 binding post *d c* watt hour meter. 75 amperes to 600 amperes, 550 volts and less

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NOTE —***The "word" constant*** is often used carelessly For this reason there has been considerable confusion as to the various meter constants Many of the name plates of Duncan watt hour meters made in the past bore the word "constant " This always referred to the watt hour constant, and had nothing to do with the reading of the register In order to avoid confusion, the name plates of Duncan watt hour meters now read "Watt hours per revolution, =

NOTE —***Watt hour, watt minute and watt second constants.*** The watt hour constant of a watt hour indicates the energy in watt hours represented by each revolution of the meter disc The watt minute constant indicates the energy in watt minutes represented by each revolution of the meter disc and is numerically equal to 60 times the watt hour constant The watt second constant indicates the energy in watt seconds represented by each revolution of the meter disc and is numerically equal to 60 times the watt minute constant The watt hour constant is the one most generally used when making tests with portable watt hour meters The watt minute constant is convenient where a standard resistance or lamp bank is used, and the watt second constant is employed in tests with indicating instruments

If the meter be read before retiring, the reading in the morning will show how much energy was consumed during the night, which will show in turn how many lamps were burning all night.

A great deal of light can be saved by placing the lamps so that they will throw the light where it is needed and by placing small lamps such as 8 candle power and 4 candle power in places where not much light is needed, such as bath rooms, halls, cellars, etc.

When the lamps get old and dim they should be replaced with new ones, as it costs about the same to burn an old lamp as a new one. An old 16 candle power lamp which is very dim will give only about 8 candle power and use about as much current as is required for a new 16 candle power. If the dim light be light enough, it should be replaced by an 8 candle power lamp, which will not consume as much power as the old 16 candle power.

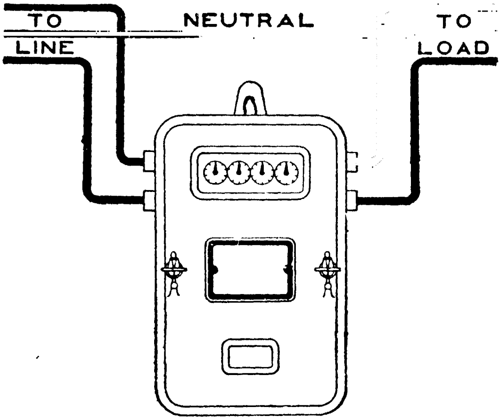


Fig. 1,461.—Connections of Duncan model E, three wire, 4 binding post *d.c.* watt hour meter, 300 amperes and less, 550 volts and less.

Watt-hour Meter Tests.—Testing of watt-hour meters is most frequently accomplished by comparing the registration of the meter under test by a Rotating Standard, that is, a standard portable watt-hour meter, usually having multiple range current and potential windings.

This standard meter, fig. 1,461-2, is connected in series with the meter under test and the revolutions of the standard are compared with the revolutions of the meter under test for the same interval of time, allowance being made in the calculations for the disc constants of the two meters.

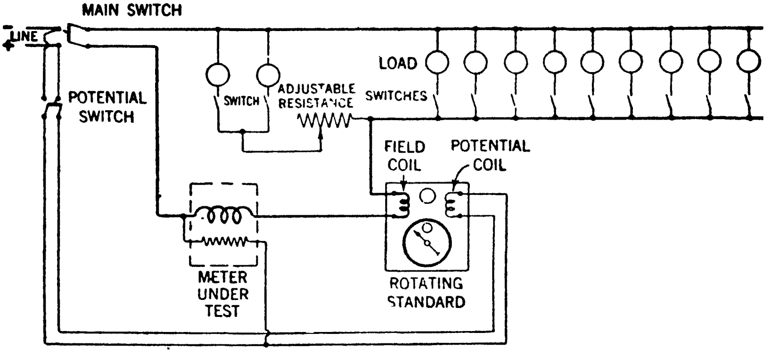


Fig. 1,461-1.—Diagram of connections for testing of watt-hour meter. A bank of lamps of various wattages serve as load. The lamps are connected to switches whereby the load may be adjusted until a suitable value is reached.

Where the value of the load is unknown it may be determined by timing the standard with a stop watch and comparing the value of the watts from the expression

$$\text{True watts} = \frac{3{,}600 \times \text{Revolutions} \times \text{Watt-hour constant}}{\text{Time in seconds}}$$

The arrangement of the test circuit is essentially as shown in fig. 1,461-1.

The rotating standard is operated by the potential switch, which starts and stops the standard, a reading of the standard is taken at the beginning and at the end of the test and the difference between these two readings gives the number of revolutions of the standard. If no correction is to be applied to the rotating standard, the per cent accuracy of the watt-hour meter under test is obtained from equation

$$\text{Per cent accuracy} = \frac{k_h \times r}{K_h \times R}$$

Where

r = revolutions of meter under test

R = revolutions of rotating standard

k_h = watt-hour constant of meter under test

K_h = watt-hour constant of rotating standard

The method may be facilitated by introducing an additional symbol, values for which may be given to the tester in tabular form

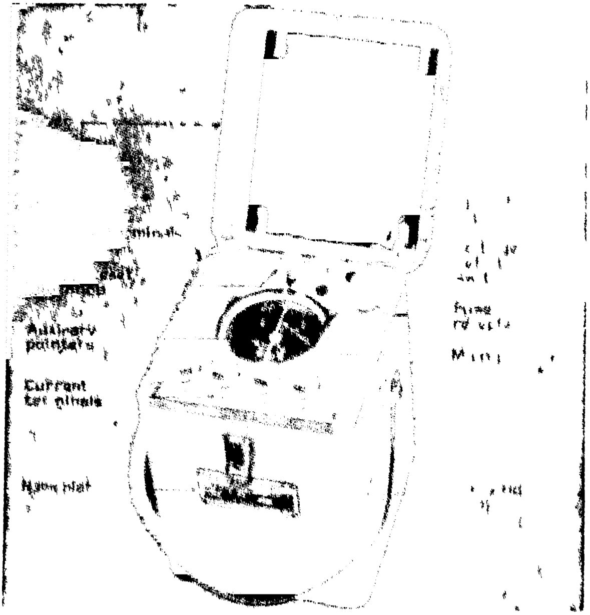


Fig 1,461 2—External view of *General Electric Company's* IB 9 portable watt hour meter standard

Let R_o = the number of revolutions the rotating standard should make when the tested meter is correct.

The numbers of revolutions of two watt-hour meters on a given load vary inversely as their disc constants, then

$$\frac{R_o}{r}=\frac{k_h}{K_h}$$

from which

$$R_o=\frac{k_h\times r}{K_h}$$

Substituting R_o in the equation for per cent accuracy

$$\text{Per cent accuracy}=\frac{R_o}{R}\times 100$$

Example.—In a certain test the rotating standard has a constant $K_h=0\ 05$ and the watt-hour meter under test has a constant $k_h=0.5$. If the number of revolutions of the meter under test, $r=2$, determine the number of revolutions of the rotating standard.

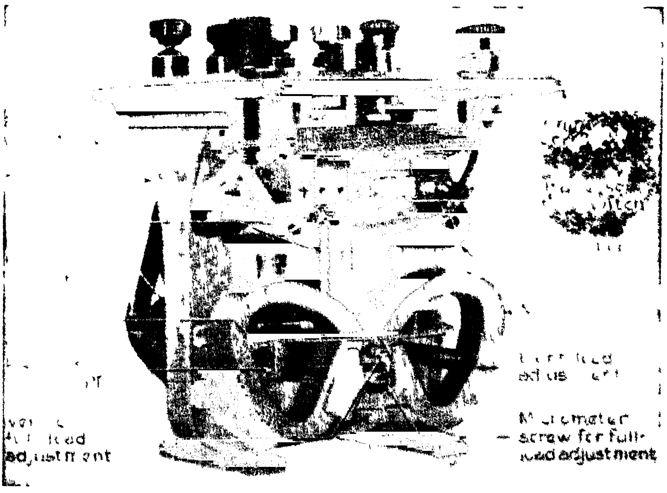


Fig. 1,461 3 —View of *General Electric Company's* IB-9 portable watt-hour meter standard removed from case

Solution.—Substituting values in formula, we obtain

$$R_o = \frac{k_h \times r}{K_h} = \frac{0.5 \times 2}{0.05} = 20$$

That is, for 2 revolutions of the meter under test, the standard should make 20 revolutions.

Example.—Assume the rotating standard in the previous example actually made 20.24 revolutions, what is the accuracy of the watt-hour meter under test?

Solution.—

$$\text{Per cent accuracy} = \frac{R_o \times 100}{R} = \frac{20 \times 100}{20.24} = 98.8\%$$

This actually means that the meter is 1.2% slow and should be speeded up slightly.

Example.—In a test of a D.C. 15 amperes watt-hour meter, the corrected average volt and ampere readings are 220 and 14.75, respectively. During the test interval 38 revolutions are counted in 53.5 seconds and the meter constant is 1.25. What is the per cent accuracy of the meter at this load?

Solution.—Average standard watts

$$W_1 = 14.75 \times 220 = 3{,}245$$

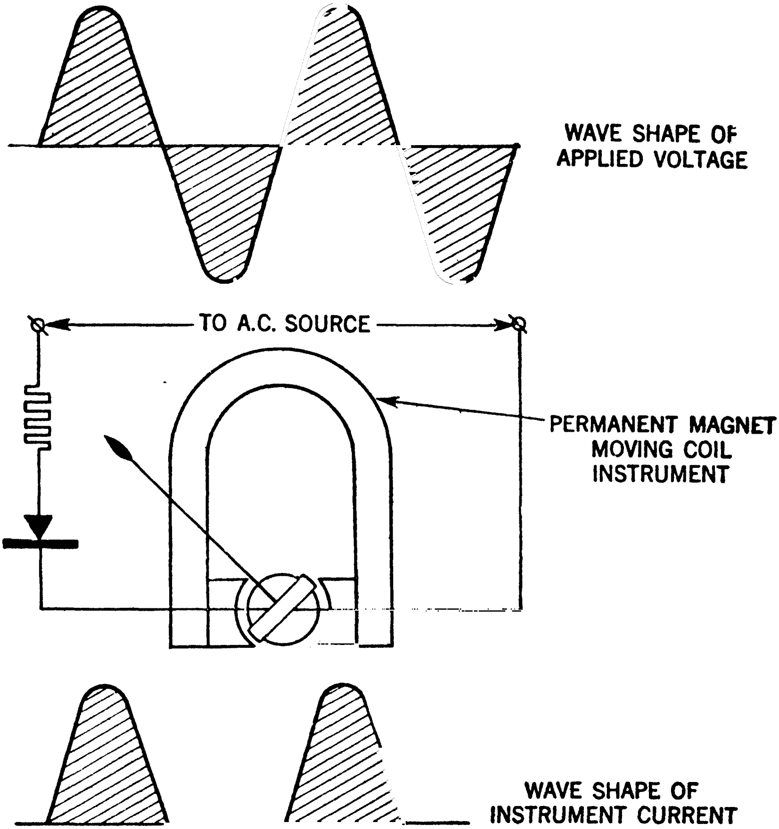
Inserting our values in the previously given equation we obtain the average meter watts as

$$W = \frac{3{,}600 \times 38 \times 1.25}{53.5} = 3{,}196$$

$$\text{Meter accuracy} = \frac{W}{W_1} = \frac{3{,}196}{3{,}245} = 0.985 \text{ or } 98.5\%$$

The Rectifier Type Instrument.—Principally the rectifier type instrument consists of a D.C. instrument of suitable characteristics to which is connected a *rectifier system* usually consisting of a four element bridge of tiny copper oxide discs, thus permitting an *alternating current* of being measured.

The copper-oxide type of rectifier instrument works on the principle that the electrical resistance of properly formed layer of copper oxide on a coated surface depends upon the polarity of the applied voltage. If such a copper-oxide plate equipped with suitable contact means be connected in the voltmeter circuit, as in fig. 1,461-5, the current flow through the permanent magnet moving coil instrument will be as shown in fig. 1,461-6.


WAVE SHAPE OF APPLIED VOLTAGE
TO A.C. SOURCE
PERMANENT MAGNET MOVING COIL INSTRUMENT
WAVE SHAPE OF INSTRUMENT CURRENT

Figs. 1,461-4 to 1,461-6.—Showing wave forms and method of connecting a D.C. permanent magnet moving coil instrument to a half-wave rectifier circuit.

As the applied voltage increases, the unidirectional current through the instrument coil will increase.

An instrument indication thus will be secured which bears a relation to the line A.C. voltage and the instrument scale can be marked in terms of A.C. volts. This arrangement is called a *half-wave rectifier.*

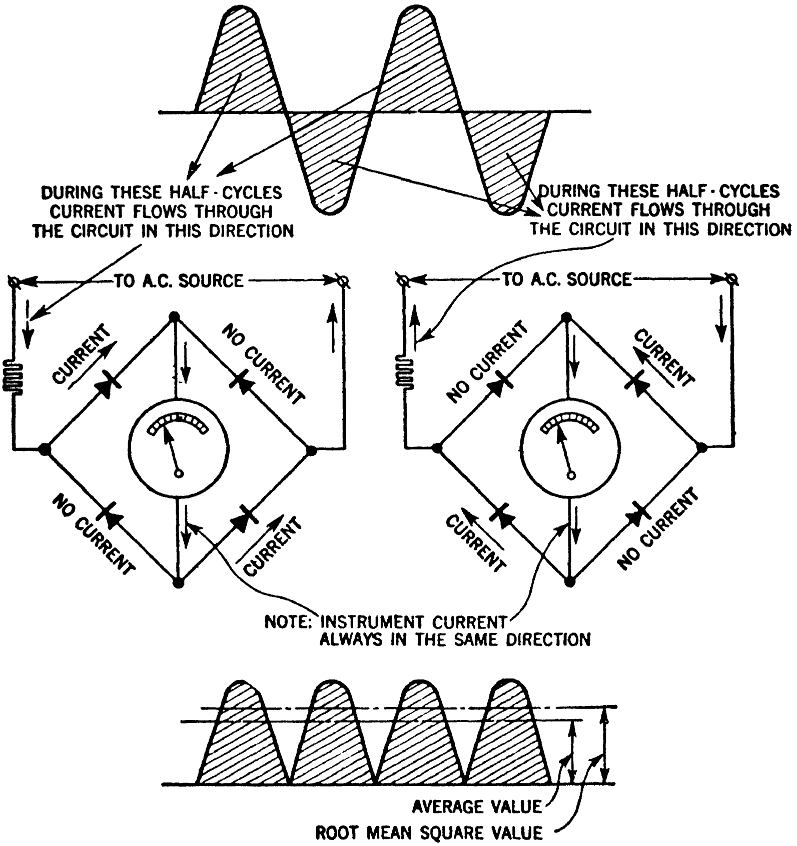
An instrument of this type, however, would not be practical for most applications, because during the negative half-cycles during which no current flows, the rectifier must withstand the full line voltage. Copper-oxide plates are not well suited to withstand such inverse voltages, and in practice this arrangement is, therefore, seldom used.

The most common method is to utilize four sets of plates connected in the manner as illustrated in figs. 1,461-8 and 1,461-9. This arrangement is commonly termed a *bridge connection.* The bridge connection has been shown twice, to show the paths taken by the current during the positive and negative half-cycles, respectively.

Although the foregoing methods of rectifier connection are most common, other arrangements are possible, and it is a simple matter to determine the method of operation by making of diagrams showing the current flow for each cycle in the manner previously illustrated.

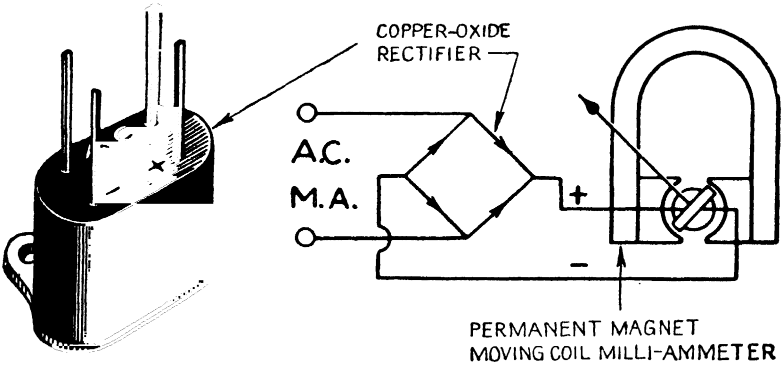
When using a rectifier instrument, it should always be borne in mind what the instrument really indicates, regardless of how the scale may be marked. A permanent magnet moving coil type instrument indicates average values, and with the rectified sine wave shown in fig. 1,461-10, the average value is shown by the lower line. On alternating current circuits, however, the root means square (*r.m.s.*) value is the quantity generally required. In fig. 1,461-10 this is shown by the higher line.

For a sine wave, the ratio $\frac{r.m.s.\text{ value}}{\text{average value}}=1.11$ and the instrument scale is marked directly in terms of the *r.m.s.* value.


DURING THESE HALF-CYCLES CURRENT FLOWS THROUGH THE CIRCUIT IN THIS DIRECTION
DURING THESE HALF-CYCLES CURRENT FLOWS THROUGH THE CIRCUIT IN THIS DIRECTION
TO A.C. SOURCE
CURRENT
NO CURRENT
NO CURRENT
CURRENT
TO A.C. SOURCE
NO CURRENT
CURRENT
CURRENT
NO CURRENT
NOTE: INSTRUMENT CURRENT ALWAYS IN THE SAME DIRECTION
AVERAGE VALUE
ROOT MEAN SQUARE VALUE

Figs. 1,461-7 to 1,461-10.—Showing wave forms and method of connection when a D.C. instrument is employed on a full-wave rectifier circuit.

For other wave shapes, this ratio is different, and hence, a rectifier instrument reads *r.m.s.* quantities correctly only on the wave shape for which it is calibrated. This point must be kept in mind when using rectifier instruments to measure non-sinusoidal quantities, such as the outputs of constant voltage transformers, etc.



Figs. 1,461-11 and 1,461-12.—Typical rectifier and circuit connection when used with a permanent magnet moving coil instrument.

Fortunately, the errors resulting from this condition are generally less than 1% of full scale value.

Some other points to be kept in mind when using rectifier-type instruments are:

(a) Some aging of the rectifiers occurs in service. For this reason, the stated accuracy of rectifier instruments is often given as ±5% of full scale. Consecutive readings, however, will often duplicate to within a few tenths of 1%.

(b) Exposure of the rectifier instrument to high temperatures such as 50°C., or to chemical vapors, such as sulphur fumes, may shorten the life of the rectifier.

(c) The circuit of the instrument itself should never be opened when the rectifier is connected to the line, since this may allow full-line voltage to be impressed on the rectifier plates, and may damage the rectifier.

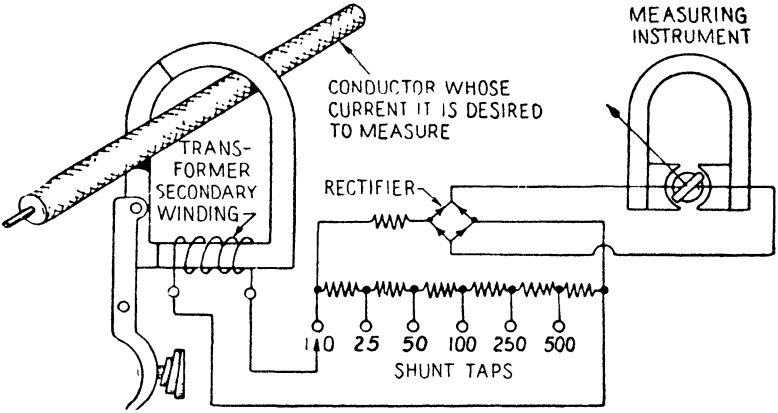

MEASURING INSTRUMENT
CONDUCTOR WHOSE CURRENT IT IS DESIRED TO MEASURE
TRANS-FORMER SECONDARY WINDING
RECTIFIER
10
25
50
100
250
500
SHUNT TAPS

FIG. 1,461-13.—Typical arrangement of a clamp-ammeter circuit with rectifier instrument.

Despite these considerations, rectifier instruments play a very useful part in present day measurements, because the permanent magnet moving coil construction gives higher sensitivity, and a more uniform scale than it is possible to secure with moving iron or dynamometer types.

Thermocouple Type Instrument.—Another device by means of which A.C. currents may be measured on a permanent-magnet moving coil instrument is known as the *thermocouple.*

It is a well known fact that if a junction of two wires of dissimilar materials (such as iron and copper-nickel, for example) be heated, and the free or *cold* ends be connected to a sensitive D.C. milli-voltmeter, a deflection of the instrument will take place. It is upon this principle that the modern thermocouple instrument operates.

When an A.C. current is made to flow through a resistance wire termed the *heater*, fig. 1,461-15, it will raise the temperature

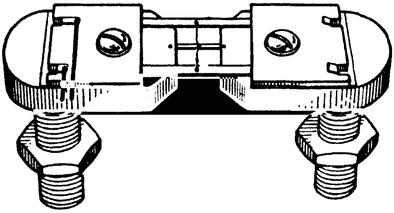


Fig. 1,461-14.—View of typical thermocouple converter. Principally the thermocouple converter consists of a small strip of platinum alloy through which the current passes, the thermocouple being heated by that current. The temperature elevation of the center of that heated conductor is then measured by a thermocouple connected to a D.C. instrument.

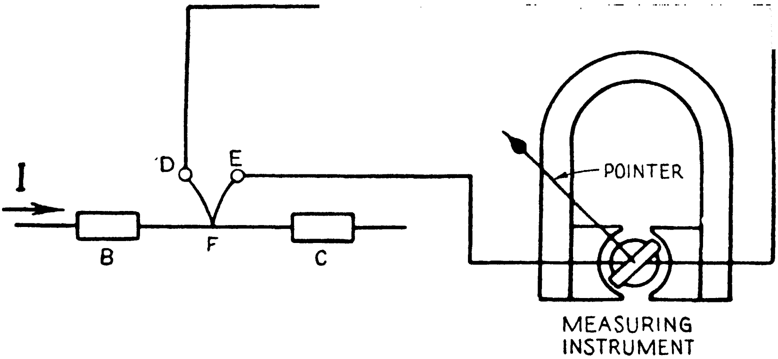


Fig. 1,461-15.—Basic type of heating element and permanent magnet moving coil for indication of direct, alternating and radio frequency currents. In the thermocouple a potential is generated in the junction **F**, of the two dissimilar metal **FD** and **FE**. The temperature of **F**, is increased over that of junction **D** and **E**, by current flowing through the wire at **BC**. This potential causes a direct current to flow through the indicating mechanism which is a function of the heating current in **BC**.

of the junction, thus sending a current through the instrument. Since the resistance of the heater remains practically constant, the instrument scale can be marked in terms of the current flowing in the heater circuit.

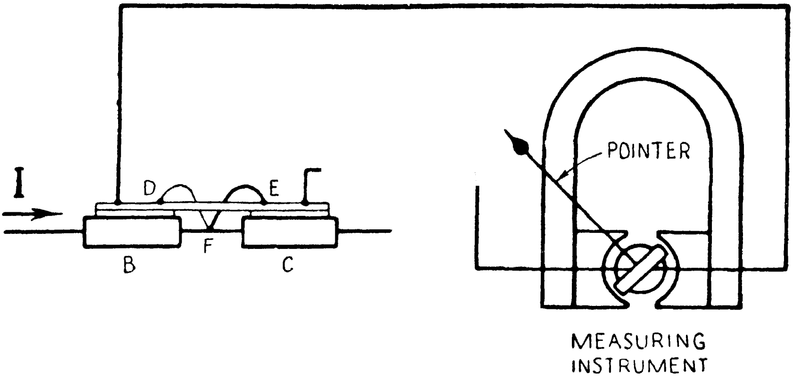


FIG. 1,461-16.—Showing arrangement used for cold junction compensation in a thermocouple instrument. Here the compensating heating element produces a thermo-electric voltage in the couple **DEF**, which is a function of the current which flows in the circuit **BC**, and causes a temperature rise at point **F**. Since the couple voltage developed is a function of the temperature difference of its hot and cold ends, this temperature difference must be caused only by the current being measured. For accurate measurements then, points **D** and **E**, must be at the mean temperature of point **B** and **C**. This is accomplished by attaching the couple ends **D** and **E**, to the center of separate copper strips whose ends are thermally in contact with **B** and **C**, but which are electrically insulated from them.

Also, as the temperature attained by the heater is proportional to the square of the current (I^2) flowing through it, the instrument scale will have the appearance indicated in fig. 1,461-17, that is, it will not be uniform, but will open up greatly as the current increases.

The voltage from a thermocouple is proportional to the difference in temperature between the heated junction and the point at which the thermocouple wires are connected to the copper leads of the instrument. Therefore, any change in the temperature of this latter connection point would result in an error in instrument indication.

To avoid errors caused by this condition, it is common practice to terminate the heater in rather massive blocks, and then bring the point at which the thermocouple leads join the copper circuit into good thermal contact with these blocks. This is usually done by connecting the leads to a thin copper plate, and separating them from the block by a thin mica strip. This is called cold-junction compensation (see fig. 1,461-16) and serves to maintain the connection at a fixed relation to the temperature of the heater.

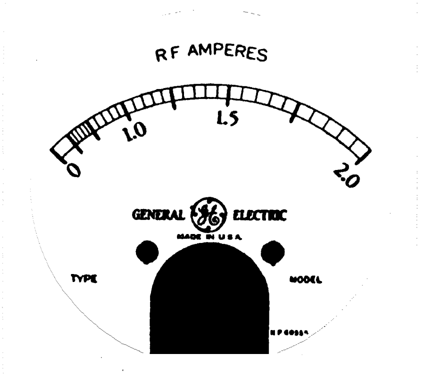


FIG. 1,461-17.—Typical scale of a standard thermocouple instrument. *Courtesy General Electric Co.*

The milli-voltmeters, used with thermocouples to measure current, must necessarily be more sensitive than those used with shunts, because the *e.m.f.* developed by a thermocouple is quite small. For example, such a thermocouple may have an output voltage of only 15 milli-volts and an internal resistance of 5 ohms. This means that thermocouple instruments should be carefully handled, since the construction is necessarily somewhat delicate.

Thermocouple instruments generally will stand 50% overload continuously but since the temperature of the heating system rises as the square of the current, overload should in general be avoided. Even if the thermocouple is not burned out there may be some evaporation of the metal in the heater which will cause the readings to be a bit higher than the true calibration.

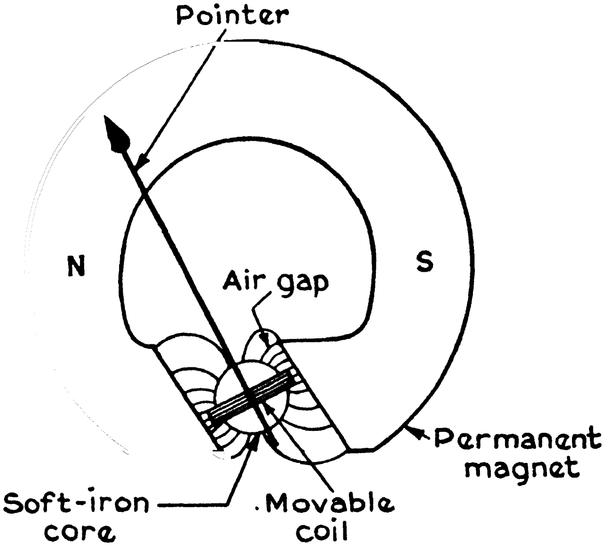


FIG. 1,461-18.—Pole pieces arrangement to obtain symmetrical scale division in a thermocouple instrument. *Courtesy General Electric Co.*

The "square law" scale of the instrument because of its unsymmetrical divisions is highly undesirable in certain applications, and while very little can be done with the thermocouple itself to overcome this, certain modifications can be made in the design of the instrument proper to give an almost linear scale indication.

The most common method to accomplish this is to so shape the magnetic pole pieces so that the magnetic flow will be less when the coil moves toward the up-scale position. A schematic view of such a design is shown in fig. 1,461-18. With the resulting scale distribution in fig. 1,461-19. This weakening of the field which lowers the instrument sensitivity as the coil moves up-scale tends to compensate for the square law relation.

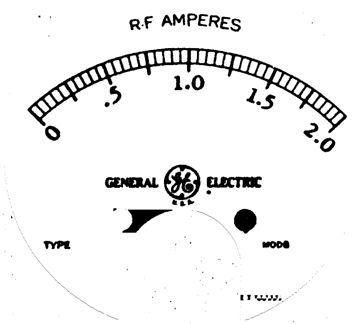


FIG. 1,461-19.—Typical expanded scale of a thermocouple instrument. *Courtesy General Electric Co.*

TEST QUESTIONS

1. *How are ammeters and volt meters classified?*
2. *Describe the moving iron type instrument.*
3. *What is the principle of the moving coil instrument?*
4. *How does the winding differ in ammeters and volt meters?*
5. *Why is a high resistance coil used with a volt meter?*
6. *How is an ammeter and volt meter connected?*
7. *Describe a solenoid or plunger ammeter.*

8. *Describe a magnetic vane instrument.*
9. *Describe an inclined coil instrument.*
10. *How does a hot wire instrument work?*
11. *What is the principle of electrostatic instruments?*
12. *Explain the construction and principle of the Thomson astatic instruments.*
13. *What are multipliers?*
14. *What is an electro-dynamometer, and how does it work?*
15. *How is the electro-dynamometer adapted to measure volts or watts?*
16. *Explain how a watt meter is installed.*
17. *Describe the Sangamo mercury motor watt meter.*
18. *How does the thermocouple and light load adjustment of Sangamo meter work?*
19. *Give a practical and accurate method of plumbing a meter.*
20. *Describe the method of testing a meter.*
21. *What is the construction of the Duncan meter?*
22. *Explain the method used in testing a watt-hour meter.*
23. *How may an alternating current be measured on a direct current instrument?*
24. *Upon what principles does the copper-oxide rectifier operate?*
25. *Describe a thermocouple instrument.*
26. *How may a thermocouple instrument be designed to obtain approximately uniform scale divisions?*

CHAPTER 38A

Direct Current Relays

Direct Current Voltage Differential Relay: (Operating Principles).—This type of relay is used where it is desired to protect against unbalanced voltage in Edison 3-wire system.

The principal parts consists of two operating coils; two plungers (one in each coil) a balance lever; two adjusting levers and springs; movable and stationary contacts; supporting frame and cover. See fig. 2.

The coils consist of potential windings and are connected into service so that one coil is connected across one side of the system between the positive and neutral lines; the other coil across the other side of the system between the neutral and the negative lines, as shown in wiring diagram fig. 1.

When the coils are energized there is generated a flux which exerts a pull on the plungers located within the hollow centers of the coil spools. With normal balanced voltage applied to the coils of the relay, an equal pull is exerted upon each plunger.

On the other hand when an unbalanced voltage occurs, the pull exerted by one coil is greater than that of the other, which action finally results in closing the contacts of the relay, which in turn will energize the definite time relay, tripping the circuit breaker through the action of the shunt trip coil.

By the use of suitable resistors this type of relay is adapted to any ordinary direct current voltage.

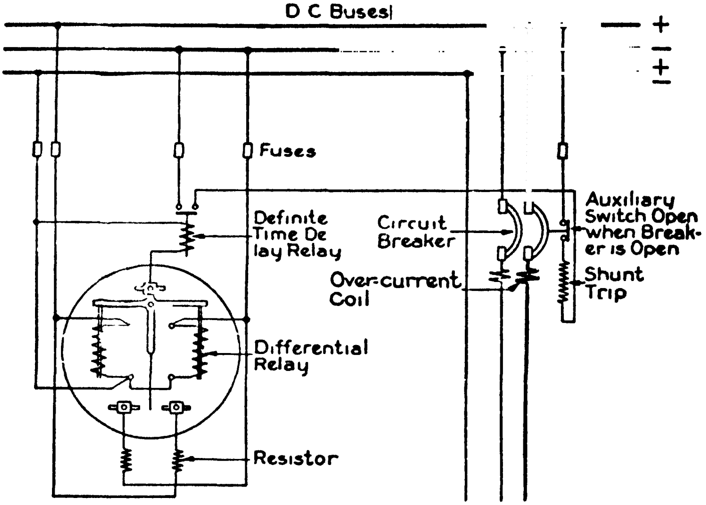


FIG 1 —Diagram of connections for voltage differential relay for protection against unbalanced voltage in Edison 3-wire system.

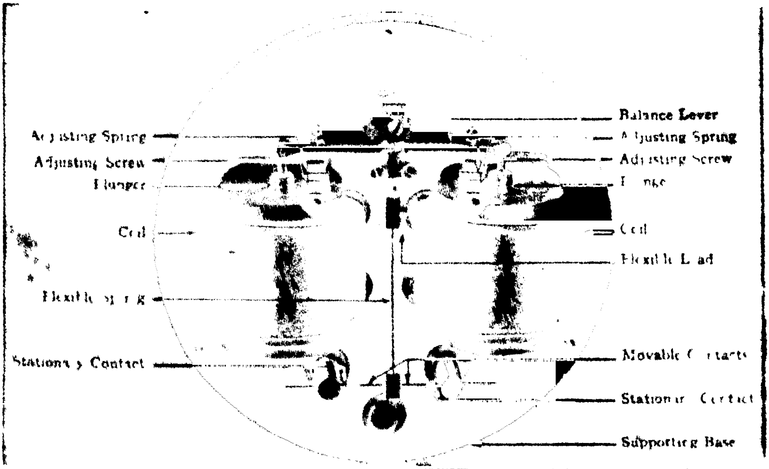


FIG 2 —Exterior view of voltage differential relay, with cover removed Diagram of connection shown in fig 1

Direct Current Power Directional Relay: (Operating Principles).—Reference to fig. 3 will assist in clearly understanding the principal of operating the direct current power directional relay. The armature is excited by the potential winding so that a magnetic flux is introduced.

The stationary magnet frames are magnetized by the current element when current is flowing. If the polarities are as in the figure, the attraction between the poles of opposite polarities tends to rotate the armature in the counter-clockwise direction.

It is pulled in the same direction by the spring and thus it is normally held against the stop whether the current is active or not, but if the flow of current reverses, the polarity of the stationary poles are reversed, and the torque exerted is also reversed. This torque depends directly upon the value of current flowing.

When the reversed current is of sufficient value, the torque exerted overcomes the pull of the spring and the armature

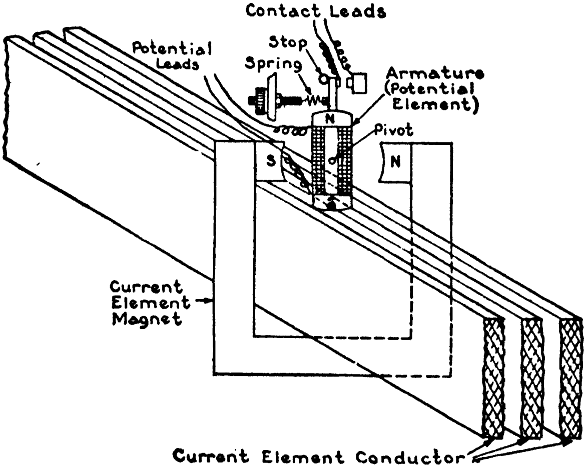


FIG. 3.—Schematic diagram illustrating operating principles of direct current power directional relay.

rotates in the clockwise direction. This action causes the movable contact to close against the stationary contact. With suitable external connections, this action trips the oil circuit breaker. See diagram fig. 4.

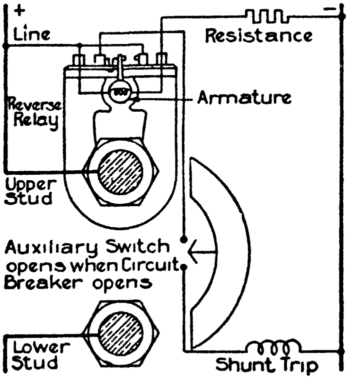


Fig 4 —Diagram of connection for direct current power directional relay. Breaker is tripped on reverse power by means of shunt trip coil

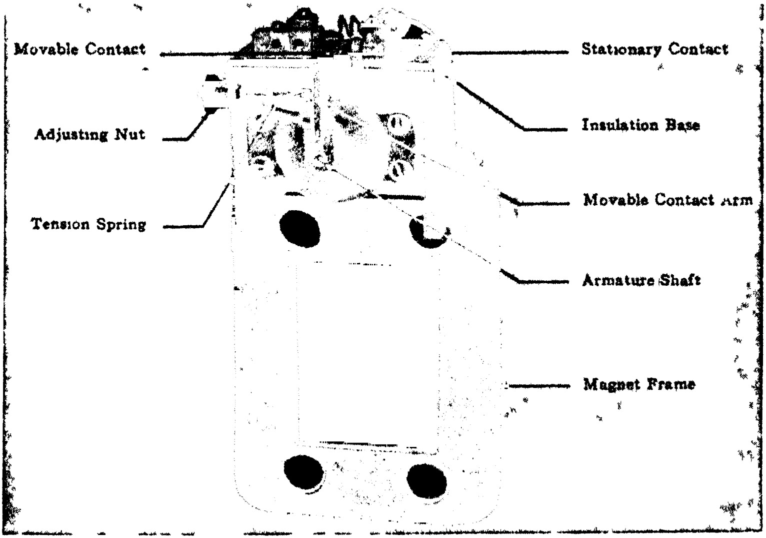


Fig 5 —Exterior view of direct current power directional relay for mounting on laminated stud.

Direct Current Combined Power Directional and Underpower Relay.—A relay of this type is applicable to any direct current circuits where very sensitive power-directional operation is required, and may be used for the following purposes:

1. For operating alarm circuits or disconnecting direct current generators in motor-generator sets when running light, due to the loss of motor supply.

2. For operating alarm circuits or disconnecting synchronous converters from the direct current bus, when the alternating-current supply fails.

3. To protect against damage which may result from a reversal of power flow.

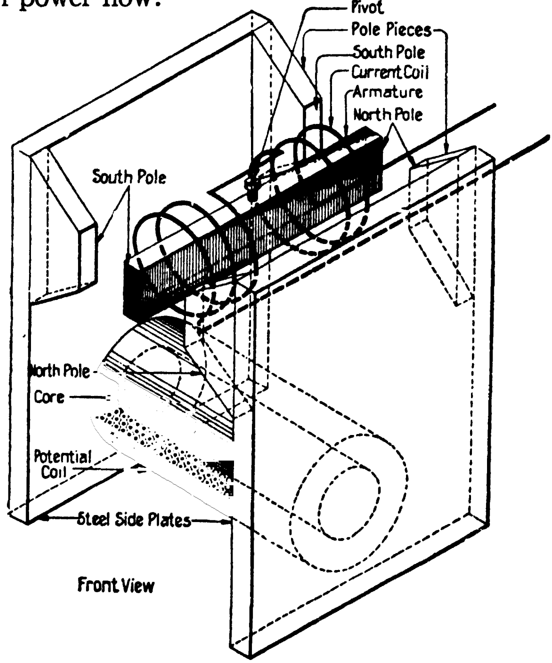


FIG. 6.—Schematic diagram of electrical element in relay.

4. In any case when power is flowing in the direction determined for the functioning of the relay, it is desired to disconnect a circuit, prevent a circuit from being disconnected, or to operate auxiliary circuits.

5. In automotive switching equipments for protecting motor-generator sets and synchronous converters against reversed flow of power, and for shutting down the machines when power demand has decreased to a pre-determined value.

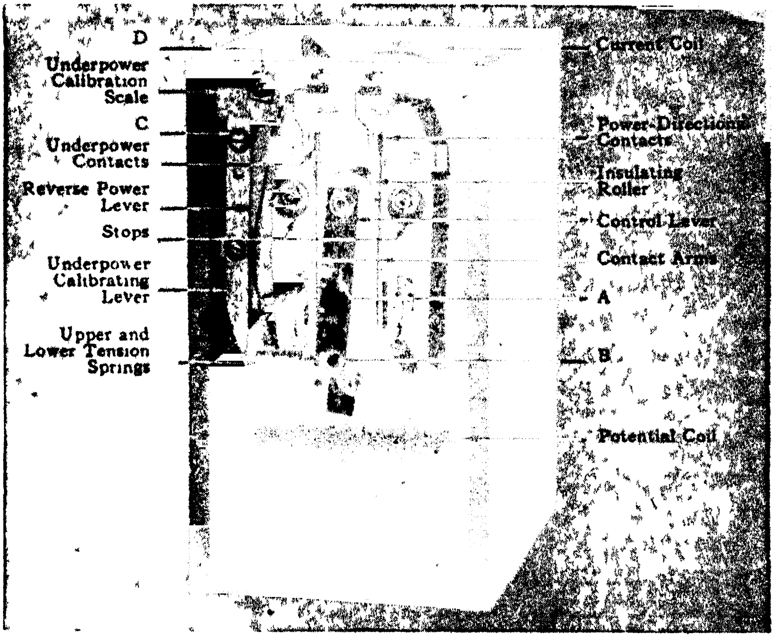


FIG 7.—Front view of under-power and power-directional relay. (Front and top cover removed)

Operating Principles.—An appreciation of the manner in which this type of relay operates can be obtained by reference to figs. 6 and 7. The current in the potential winding magnetizes the core, side plates, and pole pieces. This excitation does not cause any movement of the armature.

However, when current flows in the normal direction in the current element, the armature is magnetized, as indicated, and the magnetic reaction between the stationary and movable poles tends to rotate the armature (as viewed from the top) in the clockwise direction.

Current flowing in the opposite direction reverses the polarities of the current element and the rotating tendency is in the opposite direction.

When the armature moves to the right, the control lever rotates about the pin B, tensing the upper spring, which is connected to the power-directional lever.

When the armature moves to the left, the control lever rotates about the upper pin A, thus tensing the lower spring which is connected to the under power calibration lever.

Under normal load conditions a torque is produced which causes the armature to hold closed the under power contacts against the tension of the lower spring. When the power falls below a pre-determined value, the torque exerted is decreased, the spring overcomes the decreased pull of the armature, and the under power contacts are opened.

Upon reversal of power flow the torque reverses and the armature forces open the power-directional contacts against the tension of the upper spring.

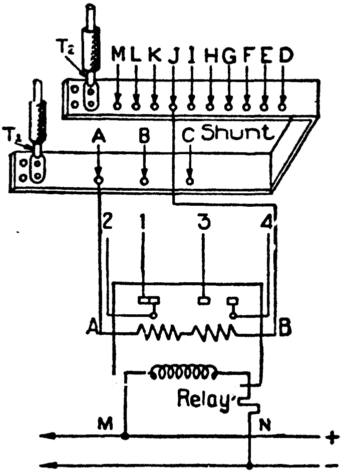
The positions of the movable armature, and consequently the contacts for the various conditions of excitation of the relay are as follows:

1. With the relay coils de-energized the control lever just touches the pins A and B, and the right hand contacts of the relay are closed; left-hand contacts open.
2. When the potential coil only is energized, the left-hand contacts of the relay are open and the right-hand contacts closed.

3. (*a*) With both coils energized, and with normal current flowing in the proper direction, the armature is moved to the left, holding the left-hand contacts closed. The right-hand contacts are also closed.

(*b*) With undercurrent flow, the armature is pulled away from the left-hand contacts allowing them to open. The other contacts remain closed.

4. When the current coil is energized with current flowing in the reverse direction, the armature is moved to the right, opening the right-hand contacts.



Note.—Leads marked 2, 1, 3 and 4 are contact connections

FIG. 8.—Diagram of connections between relay and copper shunt.

Copper Shunt.—When current to be controlled is of a value of 200 amperes and more, a special copper shunt is used, so as to obtain the same temperature co-efficient in the shunt as in the current coil of the relay. Thus the calibrations of the relay are essentially the same irrespective of the normal changes in climatic conditions. Typical shunt connections are illustrated in fig. 8.

The wiring diagram fig. 9 shows a direct-current machine connected to buses through an air circuit breaker and a copper shunt for use with the relay. The potential coil of the relay is connected in series with an auxiliary switch on the air circuit breaker.

The power-directional contacts of the relay function to open-circuit the coil of the under voltage device, when the flow of power reverses, thus causing the air circuit breaker to open. When the breaker opens the auxiliary switch also opens, and voltage is removed from the potential coil of the relay.

The current flowing having reduced to zero, the power-directional contacts automatically return to their normally closed position.

The connection to the under power contacts consists of an alarm signal which will notify operator that the power demand has decreased below a pre-determined value.

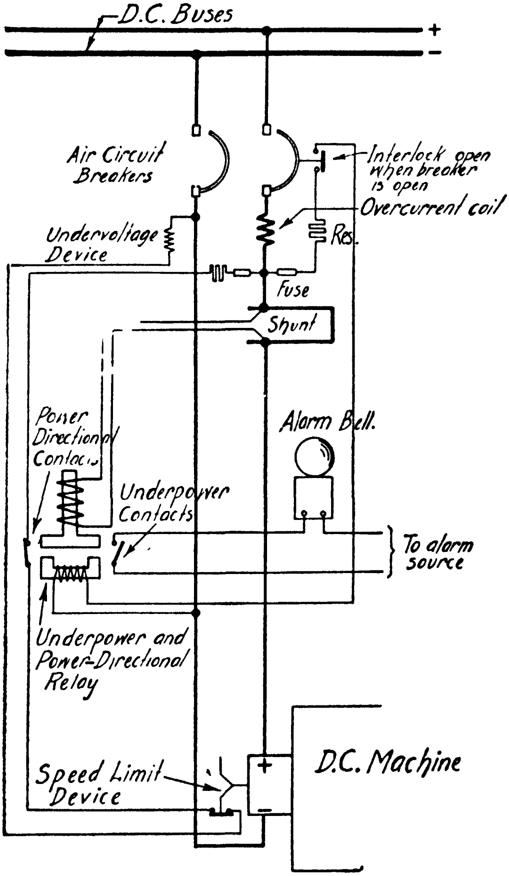


Fig. 9.—Connection diagram for under-power and power-directional relay.

CHAPTER 39

Testing and Testing Apparatus

The practical electrician frequently has to make tests of various kinds which require the rapid and accurate measurement of voltage, current and resistance. It is therefore essential that he understand the methods employed in testing and the operation of the instruments used.

Most tests are made with a galvanometer, and the devices such as resistances, switches, etc., which are used in connection with the galvanometer may be obtained put up in a neat and substantial box together with the galvanometer, the combination being called a "testing set." Numerous forms of testing set are illustrated in this chapter.

The construction, use, and operation of the various types of galvanometer have been explained in chapter thirty-seven. Ammeters and volt meters, which are simply special forms of galvanometer, and which are largely used are fully described in the preceding chapter.

Pressure Measurement.—An electromotive force has been defined as that which causes or tends to cause a current; it is analogous to water pressure; potential difference corresponds to difference of level. The *total* electromotive force of a circuit is independent of resistance or current, and cannot be limited to mean the fall of pressure between any two points, as for instance the terminals of a battery.

If the pressure of a battery be two volts when measured on open circuit by a static voltmeter, there will still be two volts on closed circuit, but there will now be a loss of pressure through the internal resistance of the battery and the voltage across the terminals will be less than the *total* voltage. The static volt meter, never closing the circuit, actually measures the total voltage.

Ques. What error is introduced in measuring the pressure of a battery with an ordinary volt meter?

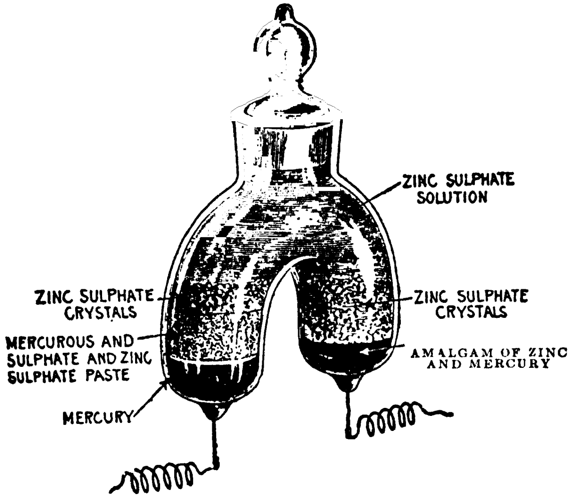

ZINC SULPHATE SOLUTION
ZINC SULPHATE CRYSTALS
ZINC SULPHATE CRYSTALS
MERCUROUS AND SULPHATE AND ZINC SULPHATE PASTE
AMALGAM OF ZINC AND MERCURY
MERCURY

FIG. 1.462.—Clark cell (Kahle's modification of the Rayleigh H form), the standard for the International volt. The cell has for its positive electrode, mercury, and for its negative electrode, amalgamated zinc. The electrolyte consists of a saturated solution of zinc sulphate and mercurous sulphate. The pressure is 1.434 volts at 15° C , and between 10° C. and 25° C. the pressure decreases .00115 of a volt for each increase of 1° C. The containing glass vessel consists of two limbs, closed at bottom and joined above to a common neck fitted with a ground glass stopper. The diameter of the limbs should be at least 2 cms., and their length at least 3 cms. The neck should be not less than 1.5 cms. in diameter. At the bottom of each limb a platinum wire of about .4 mm. in diameter is sealed through the glass. To set up the cell, place mercury in one limb, and in the other hot liquid amalgam, containing 90 parts mercury and 10 parts zinc. The platinum wires at the bottom must be completely covered by the mercury and the amalgam, respectively. On the mercury, place a layer 1 cm. thick of the zinc and mercurous sulphate paste. Both this paste and the zinc amalgam must be covered with a layer of the neutral zinc sulphate crystals 1 cm. thick. The whole vessel must then be filled with the saturated zinc sulphate solution, and the stopper inserted so that it will just touch it, leaving, however, a small bubble to guard against breakage when the temperature rises. Before finally inserting the glass stopper a strong alcoholic solution of shellac is applied to the upper edge, after which the stopper is pressed firmly in place.

Ans. Since the measurement is made on *closed circuit* the reading does not give the total pressure of the battery.

The error is very slight because the resistance of the volt meter is very high and the current so small that the loss of pressure in the battery can be neglected.

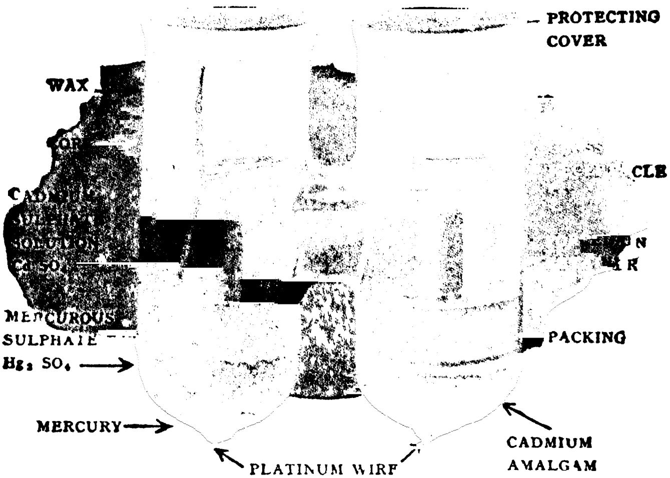


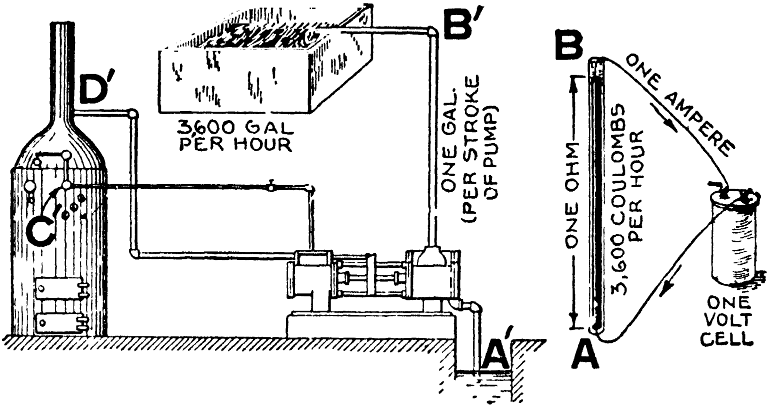
FIG 1,463 —Weston Cadmium Cell It is made in two forms, one known as the Weston normal cell, in which the solution of cadmium sulphate is saturated at all temperatures at which the cell may be used The other, known as the Weston standard cell, in which the cadmium sulphate solution is unsaturated at all temperatures above 4° C The Weston normal cell, or saturated form is slightly affected by changes in temperature, but, on account of the fact that it can be accurately reproduced, it was adopted by the London Conference in 1908, as a convenient voltage standard The value of its voltage suggested by the committee of the London Conference on Electrical Units and Standards, and adopted by the Bureau of Standards at Washington, Jan 1st, 1911, is 1 0183 International volts at 20° C. At any other temperature its voltage is

$$E_t = E_{20} - 0000406 (t - 20) - 00000095 (t - 20)^2 + 0000000 (t - 20°)^3$$

The Weston standard cell, or unsaturated form is practically unaffected by changes in temperature and is the form most commonly used for laboratory work and general testing. The average pressure of this form is 1 0187 Int volts

Ques. Define the International volt.

Ans. *It is the electromotive force that, steadily applied to a conductor whose resistance is one International ohm, will produce a* *current of one International ampere, and which is represented sufficiently well for practical use by* $\frac{1,000}{1,434}$ *of the voltage between the poles of the Clark cell at a temperature of* 15° *C., when prepared as in fig.* 1,462.



FIGS. 1,464 and 1,465.—Steam pump showing by hydraulic analogy the difference between amperes and coulombs. If the current strength in fig. 1,465 be one ampere, the quantity of electricity passing any point in the circuit per hour is 1 × 60 × 60 = 3,600 coulombs. The *rate* of current flow of one ampere here illustrated may be compared to the rate of discharge of a pump as in fig. 1,464. Assuming the pump to be of such size that it discharges a gallon per stroke and is making 60 strokes per minute, the quantity of water discharged per hour (coulombs in fig. 1,465) is 1 × 60 × 60 = 3,600 gallons. Following the analogy further (in fig. 1,465), the pressure of one volt is required to force the electricity through the resistance of one ohm between the terminals A and B. In fig. 1,464, the boiler must furnish steam pressure on the pump piston to overcome the friction (resistance) offered by the pipe and raise the water from the lower level A′, to the higher level B′. The difference of pressure between A and B in the electric circuit corresponds to the difference of pressure between A′ and B′. The cell furnishes the energy to move the current by maintaining a difference of pressure at its terminals C and D, similarly, the boiler furnishes energy to raise the water by maintaining a difference of pressure between the steam pipe C, and exhaust pipe D′.

The relation between the units volt, ampere and ohm, is shown graphically in figs. 1,464 and 1,465.

Current Measurement.—It is necessary to adopt some arbitrary standard in order to compare currents of different strengths. The term *strength of a current*, or current strength means the *rate of flow past any point in the circuit in a given unit of time.*

The unit of current, called the *ampere*, is defined as *the unvarying current which, when passed through a solution of nitrate of silver in water* (15 *per cent. by weight of the nitrate) deposits silver at the rate of* .001118 *gramme per second.*

Ques. How much copper or zinc will one ampere deposit in one second?

Ans. .0003286 gramme of copper in a copper voltameter, or .0003386 gramme of zinc in a zinc voltameter.

Ques. What is the difference between an ampere and a coulomb?

Ans. An ampere is the unit *rate of flow* of the current, and a coulomb is the unit *quantity* of electricity, that is, the ampere is the rate of current flow that will deposit .0003286 gramme of copper in one second and a coulomb is the *quantity* of electricity that passes a given point in one second when the current strength is one ampere.

In other words a coulomb is an *ampere second.*

Example.—If an arc lamp require a current of 8 amperes, how much electricity does it consume per hour?

Since one coulomb = one ampere second, the quantity of electricity consumed per hour is

$$\left.\begin{matrix}\text{amperes}\\8\end{matrix}\right\}\times\left\{\begin{matrix}\text{seconds}\\60\times60\end{matrix}\right\}=28{,}800\text{ coulombs.}$$

NOTE.—***A galvanometer*** is not a measuring instrument and should not be used as such, except in cases where no better method is available; for example, the measurement of insulation resistance. Where circumstances are such that a galvanometer must be used as a measuring instrument, it should be calibrated with such frequency as to become, in effect, a transfer instrument.

Voltameter.—A voltameter is an electrolytic cell employed to measure an electric current by the amount of chemical decomposition the current causes in passing through the cell. There are two classes of voltameter:

1. Weight voltameters;
2. Gas voltameters.

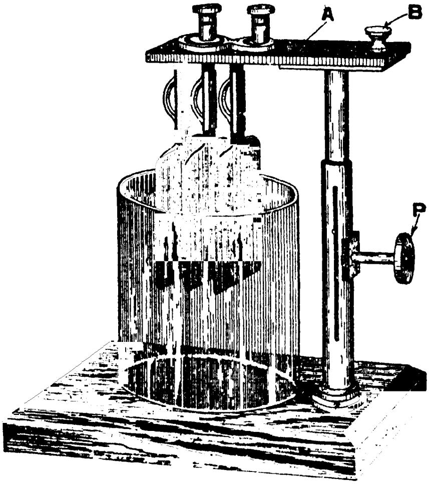


FIG. 1,466.—Queen weight voltameter for determining the strength of current by the weight of metal deposited in a given time. The two outside plates form the anode and are joined together and to one binding post, while the cathode is placed between them and connected to the other binding post. The cathode thus receives a deposit on both sides. An adjustable arm serves to lower the plates into the electrolyte. To calculate the strength of an unknown current which has passed through a weight volt meter, *divide the gain in weight by the number of seconds the current flows through the instrument and by the weight deposited by one ampere in one second.* That is, (for copper voltameter) current strength in amperes = gain in weight ÷ (time in seconds × .0003286).

Ques. What is the difference between these two classes of voltameter?

Ans. In one, the current strength is determined by the weight of metal deposited or weight of water decomposed, and in the other by the volume of gas liberated.

Fig. 1,466 shows a weight voltameter and fig. 1,467 a gas voltameter.

Ques. How should the plates of a weight voltameter be treated before use?

Ans. They must be thoroughly cleaned and polished with sand paper, the sand being afterwards removed by placing them in running water. *The fingers must not be placed on any part of the plate which is to receive the deposit.*

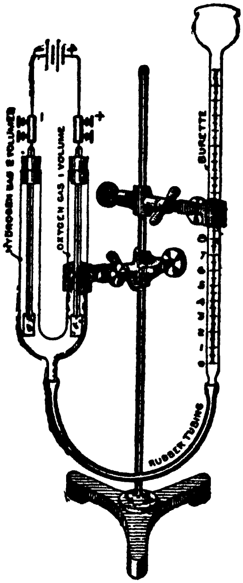


FIG 1,467 —Gas voltameter for determining the strength of current by the volume of gas evolved To use, connect up as shown in the illustration Adjust so that the zero position of the burette is about one-half inch below the level of the top of the U tube Pour acidulated water into the mouth of the burette till the water in the U tube is about one-half inch from the top With the electrodes inserted through the corks, *carefully* place each one in position by giving a slight twist to the right as the cork enters The water level in the U tube and burette should now be the same or further adjustment must be made to attain this result The level in the burette does not necessarily have to correspond with the zero graduation, but must not be below it Unclamp the burette and hold it nearly horizontal The liquid will not run out if the corks be tight, accordingly this is the *air leakage test* Attach the connectors and wires from the current source (which should have a pressure of 2 or more volts) placing a switch in the circuit. When th switch is closed, bubbles of gas will rise in the U tube from both electrodes, displacing the water and forcing it up the burette Hydrogen will be liberated over the negative electrode, and oxygen over the positive electrode in the proportion of twice as much hydrogen as oxygen. To calculate the current strength, *divide the volume of gas liberated by the time in seconds, and by the volume of gas liberated (in cubic centimeters) by one ampere in one second and by* .1733; that is: amperes = volume of gas liberated ÷ (time in seconds × .1733).

Ques. What form of voltameter has been selected to measure the International ampere?

Ans. The silver voltameter arranged as here specified.

The cathode on which the silver is to be deposited shall take the form of a platinum bowl, not less than 10 cms. in diameter, and from 4 to 5 cms. in depth.

The anode shall be a disc or plate of pure silver some 30 sq. cms. in area, and 2 or 3 cms. in thickness. This shall be supported horizontally in the liquid near the top of the solution by a silver rod riveted through its center.

To prevent the disintegrated silver which is formed on the anode falling upon the cathode, the anode shall be wrapped around with pure filter paper, secured at the back by suitable folding.

The liquid shall consist of a neutral solution of pure silver nitrate containing about 15 parts by weight of the nitrate to 85 parts of water.

Ques. What is the value of the International ampere as measured with the silver voltameter?

Ans. The International ampere is represented sufficiently well for practical use by the unvarying current which, when passed through a silver voltameter (as described above) deposits *silver at the rate of* .001118 *gramme per second.*

Ohm's Law and the Ohm.—The various tests here described depend for their truth upon the definite relation existing between the electric current, its pressure, and the resistance which the circuit offers to its flow.

This relation was fully investigated by Ohm in 1827. Using the same conductor, he proved not only that the current varies with the pressure, but that it varies in direct proportion.

Ohm's law has already been discussed in a previous chapter and the several ways of expressing it are repeated here for convenience:

1. $\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$;

2. Volts = amperes × ohms;

3. $\text{Ohms} = \dfrac{\text{volts}}{\text{amperes}}$

Various values have been assigned, from time to time, to the ohm or unit of resistance, the unit in use at the present time being known as the *International ohm.* This was recommended

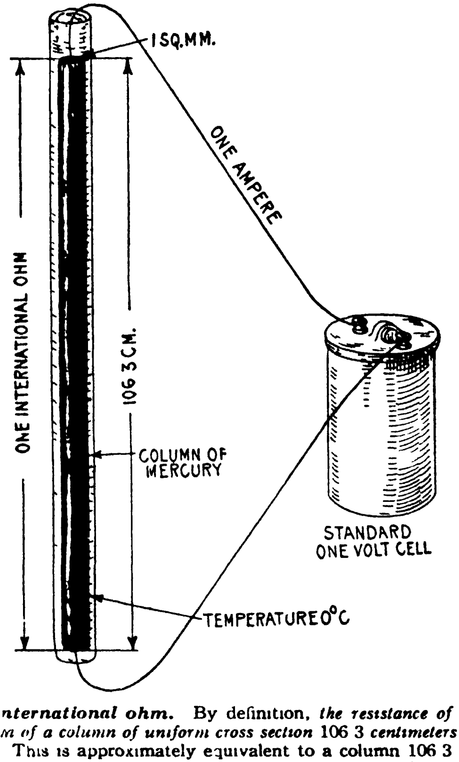


Fig. 1,468—The ***International ohm.*** By definition, ***the resistance of* 14 452 *grammes of mercury in the form of a column of uniform cross section* 106 3 *centimeters in length, at a temperature of* 0° C** This is approximately equivalent to a column 106 3 *cm* long, having a uniform cross section of 1 sq mm In the figure the resistance of the external circuit and the standard one volt cell is assumed to be zero at the meeting of the British Association in 1892, was adopted by the International Electrical Congress held in Chicago in 1893, and was legalized for use in the United States by act of Congress in 1894. The International ohm is graphically defined in fig. 1,468. The previous values given to the ohm which were more or less generally accepted are as follows:

The Siemens' Ohm.—*A resistance due to a column of mercury* 100 *cm. long and* 1 *sq. mm. in cross section at* 0° *C.*

B. A. (***British Association***) ***Ohm.***—*A resistance due to a column of mercury approximately* 104.9 *cm. long and* 1 *sq. mm. in cross section at* 0° *C.*

Legal Ohm.—*A resistance due to a column of mercury* 106 *cm. long and* 1 *sq. mm. in cross section at* 0° *C.* This unit was adopted by the Paris conference of 1884.

OHM TABLE*

	Date	**International Ohm**	Legal Ohm	B. A. Ohm	Siemens' Ohm
International Ohm	1893–4	1.	1.0028	1.0136	1.0630
Legal Ohm	1884	.9972	1.	1.0107	1.0600
B. A. Ohm	1864	.9866	.9894	1.	1.0488
Siemens' Ohm	....	9407	.9434	.9535	1.

Practical Standards of Resistance.—The column of mercury as shown in fig. 1,468, is the recognized standard for resistance, however, in practice, it is not convenient to compare resistances with such a piece of apparatus, and therefore secondary standards are made up and standardized with a great degree of precision. These secondary standards are made of wire. The material generally used being manganin or platinoid.

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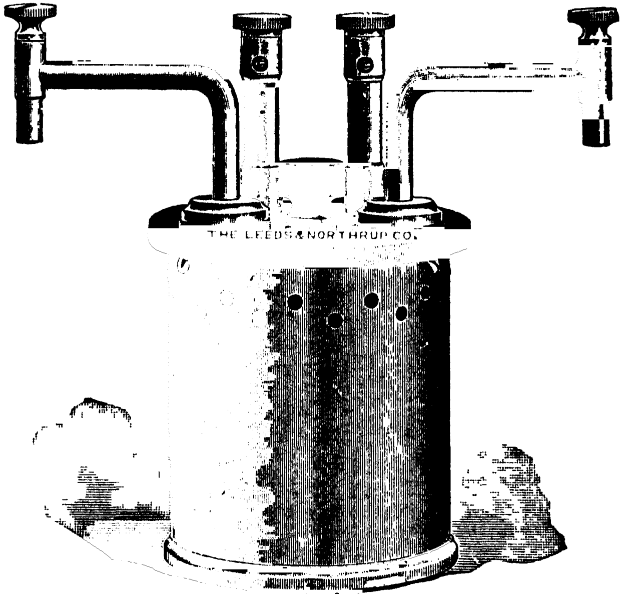
*NOTE.—***In the above table*** to reduce, for instance, British Association ohms to International ohms, multiply by .9866, or divide by 1.0136; to reduce legal ohms to International ohms, multiply by .9972 or divide by 1.0028 etc.

Resistance Measurement.—*Resistance is that which offers opposition to the flow of electricity.* Ohm's law shows that the strength of the current falls off in proportion as the resistance in the circuit increases. This gives a basis for measuring resistance.



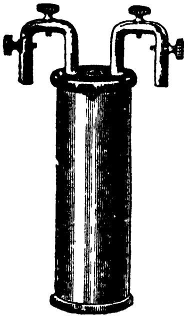


FIG. 1,469.—Leeds and Northrup resistance standards, National Bureau of Standards type, hermetically sealed in a neutral oil to overcome changes due to atmospheric conditions. Accuracy $\frac{1}{100}$ of 1% for total energy of $\frac{1}{10}$ watt $\frac{1}{25}$ of 1% up to 1 watt. The principal requirement in a resistance standard is that its resistance value be definite within the required accuracy, under definite conditions For the sake of convenience the value of a standard should be definite under all usual conditions of normal use. However, for work of the utmost accuracy, it is often necessary to resort to the use of temperature control by means of oil baths.

FIG. 1,470 —Leeds and Northrup standard resistance Reichsanstalt type .1 ohm; adjusted at 20° C. Low resistance standards may be properly divided into two classes: 1, those which are designed primarily as resistance standards, and 2, those designed as current carrying standards. Those of the first mentioned class are often used to measure currents up to their capacity. The above standard has both pressure and current terminals. The binding posts for the former are mounted on high posts so as to be easily accessible when the standard is immersed in oil. When used as a resistance standard of precision, it should not be subjected to a current of more than one ampere, and when used as a current carrying standard of lesser accuracy, a current of 2 or 3 amperes may be used.

There are various methods by which an unknown resistance may be measured, as by the:

1. Direct deflection method;
2. Method of substitution;
3. Fall of potential method;
4. Differential galvanometer method;
5. Drop method;
6. Volt meter method;
7. Wheatstone bridge method.

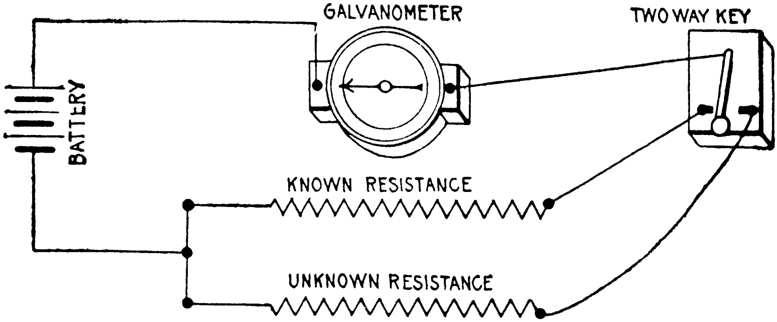


FIG. 1,471.—Direct deflection method of testing resistances; a useful and simple method which may be used in numerous tests. Galvanometer readings are taken through the known and unknown resistances, and the current being proportional to the deflections, the value of the unknown resistance is easily calculated.

Direct Deflection Method.—This method is based on the fact that the greater the current through a galvanometer the greater the deflection of the needle; it is a simple method and is capable of extended application.

The apparatus required consists of battery, galvanometer, known resistance, and double contact key. The connections are made as in fig. 1,471.

The known resistance is put in circuit with the galvanometer and after noting the deflection, the key is moved in order to cut out the known resistance and throw into circuit the unknown resistance. The deflection of the galvanometer is again noted and compared with the first deflection.

If the deflections be proportional to the current, the unknown resistance will be as many times the known resistance as the deflection with the known resistance is greater than the deflection with the unknown resistance.

Method of Substitution.—This is the simplest method of measuring resistance. The resistance to be measured is inserted in series with a galvanometer and some constant source of

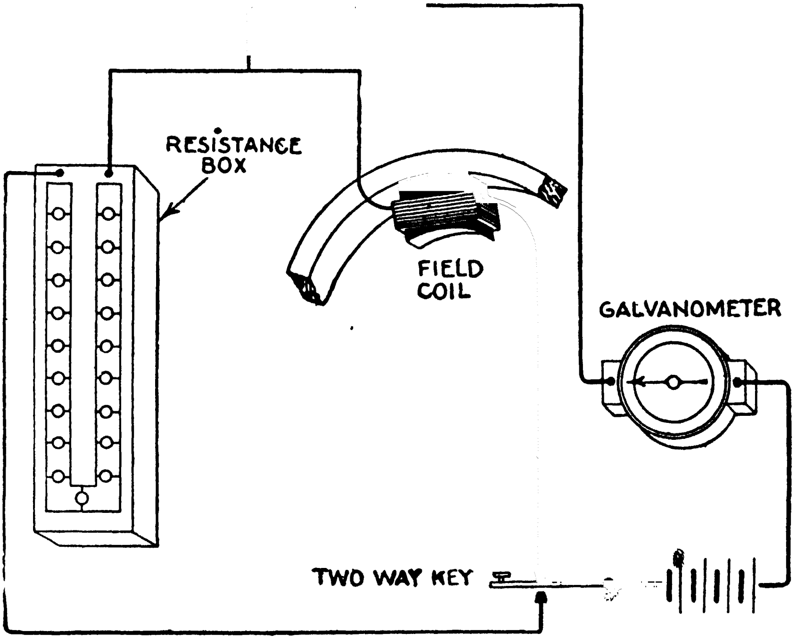


FIG. 1,472 —Substitution method of testing resistances. The connections and apparatus are the same as in fig 1,471, except that a resistance box is used in place of the known resistance In making the test, first note deflection with unknown resistance in circuit, then press key so that the current will pass through the resistance box, and adjust the resistance in the box so that the deflection of the galvanometer is about the same as with the unknown Now switch from this circuit to the other, changing the resistance in the box until equal deflections are obtained. When this obtains, the resistance in the box is the same as the resistance being tested.

current, and the galvanometer deflection noted. A known adjustable resistance is then substituted for the unknown and adjusted till the same deflection is again obtained. The value

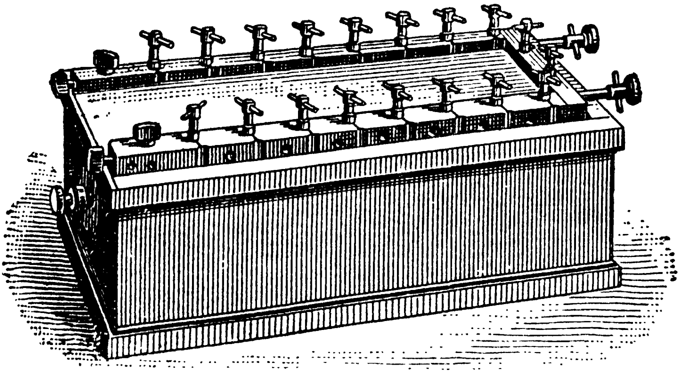


FIG. 1,473.—Ordinary resistance box. It contains a set of standard resistances consisting of coils of insulated wire having low conductivity and small temperature coefficient. The ends of the coils are joined to the section of the bar between the plugs. The insertion of a plug cuts out a coil. In using care should be taken to put the plugs in with a slight twist so that there shall be no resistance introduced by poor contact.

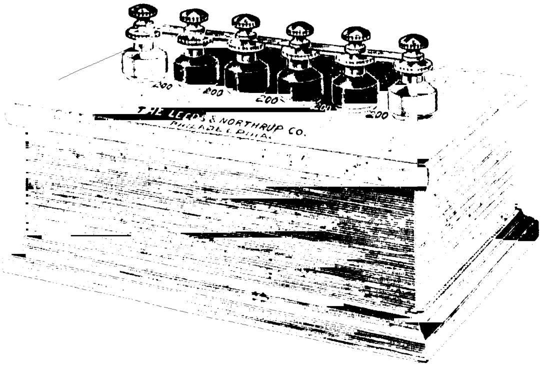


FIG. 1,474.—Megohm box or set of standard high resistances. The box contains five resistances of 200,000 ohms each. The six pillars are petticoat insulated, the resistances being placed between each pair of pillars. There is a double contact post on top of each pillar so that these can be connected together with copper links.

of the adjustable resistance thus obtained is equal to that of the resistance being tested.

Ques. What kind of adjustable resistance is used in making the above test?

Ans. A resistance box.

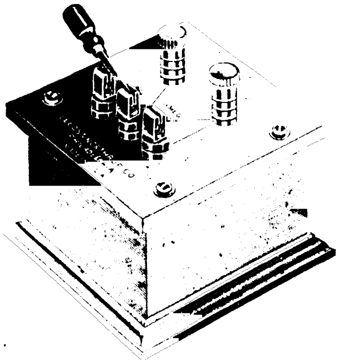


FIG. 1,475.—Leeds and Northrup Standard high resistance box, 100,000 ohms equipped with short circuiting switch. When the switch is thrown to the right the box is short circuited and when thrown to the left the resistance of 100,000 ohms is placed in the circuit.

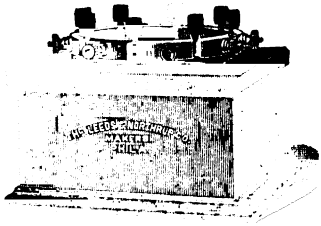


FIG. 1,476.—Standard resistance box; 100,000 ohms, in four units of 10,000, 20,000, 30,000, and 40,000 ohms. An "infinity" plug separates each coil from the ones adjacent. Segments are elevated from the hard rubber top by special washers in order to increase insulation. Binding posts are so arranged as not to be in the way when plugs are used.

Ques. Describe a resistance box.

Ans. It consists of a box containing numerous resistance coils with their ends connected to terminals and provided with plugs so that they may be thrown into or out of circuit at will, thus varying the resistance in the circuit.

Fall of Potential Method.—This is a very simple method of measuring resistances, and one that is convenient for practical work in electrical stations because it requires only an ammeter, volt meter, battery and switch—apparatus to be found in every station. The connections are made as shown in fig. 1,477.

In making the test the ammeter and volt meter readings are taken at the same time, and the unknown resistance calculated from Ohm's law. Accordingly, since:

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}} \quad \text{(1)}$$

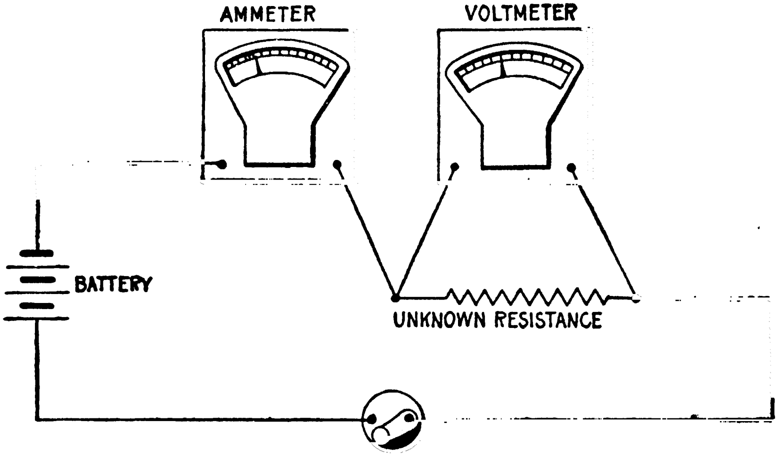


FIG. 1,477.—Fall of potential method of testing resistances; a convenient method for testing at stations, requiring only the usual instruments to be found at a station. The resistance of the volt meter must be very high, otherwise the test must be made as in fig. 1,478.

solving for the resistance,

$$\text{ohms} = \frac{\text{volts}}{\text{amperes}} \quad \text{(2)}$$

Example.—If in fig. 1,477 the readings show 6 volts and 2 amperes how many ohms is the resistance being tested?

Substituting in formula (2)

$$\text{ohms} = \frac{6}{2} = 3$$

Ques. Can this test be made with any kind of volt meter?

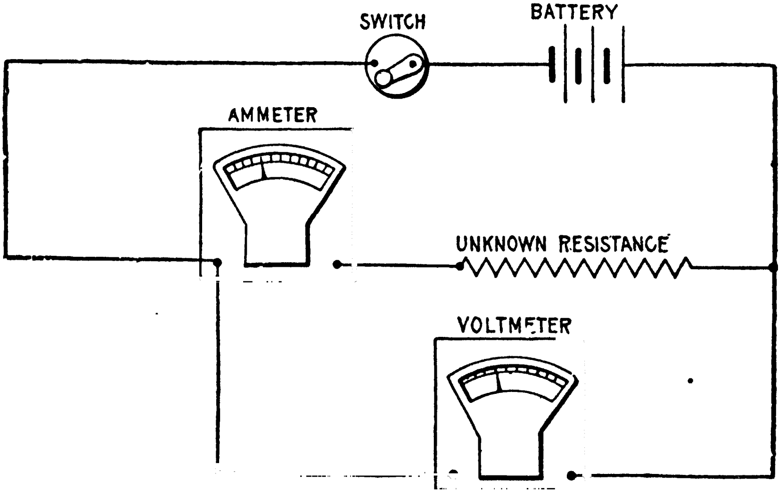


Fig. 1,478.—Fall of potential method of testing resistances; diagram showing connections for testing with low resistance volt meter. The resistance measured with this connection will be the sum of the resistances of the coil and the ammeter. The resistance of the ammeter is usually known and can be subtracted from the sum to obtain the required resistance.

Ans. Its resistance must be very high to avoid error. When a volt meter having small resistance is used, it should be connected so as to measure the fall of pressure across both ammeter and unknown resistance as shown in fig. 1,478.

Differential Galvanometer Method.—This is what is known

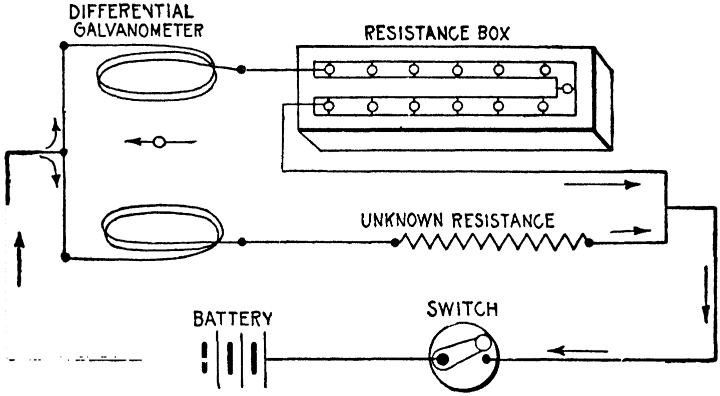


FIG. 1,479.—Differential galvanometer method of testing resistance. In making the test, the resistance box is adjusted till the galvanometer needle shows no deflection. When this condition obtains, the resistance in circuit in the resistance box is equal to the unknown resistance, hence, a reading of the box gives the value of the unknown resistance.

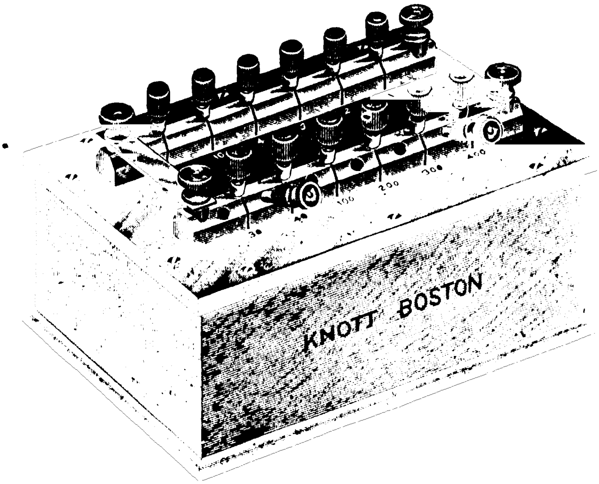


FIG. 1,480.—Knott Traveling Plug resistance box, range 1 to 1,110 ohms. This box is provided with brass blocks and ebonite top. Contains 12 coils ranging from 1 to 400 ohms, with total resistance of 1,110 ohms. The usefulness of this box is increased by the addition of two traveling plugs facilitating its use in the comparison of electromotive force of batteries, and other tests.

as a *nil* or zero method, that is, a method of making electrical measurements in which comparison is made between two quantities by reducing one to equality with the other, the absence of deflection from zero of the instrument scale showing that the equality has been obtained.

The test is made with a differential galvanometer, and resistance box connected as in fig. 1,479. The current then will divide so that part of it flows through the resistance being tested and around one set of coils of the galvanometer while the other part will flow through the resistance box and the other set of coils as indicated.

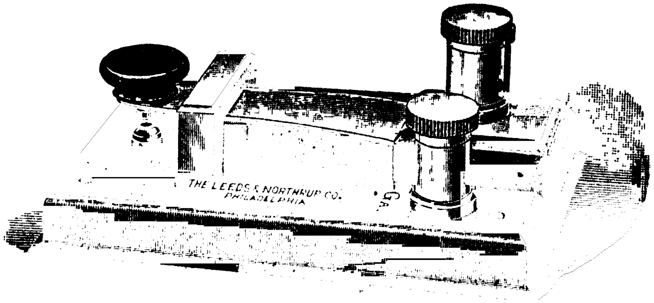


Fig. 1,481.—Single contact and short circuiting key. This key is intended especially for use with D'Arsonval galvanometers in zero, deflection methods. The key is connected in circuit with the galvanometer so that whenever the key is not depressed, the galvanometer is short circuited, and its oscillations quickly damped out by the currents induced in its coil.

When the resistance box has been so adjusted that its resistance is the same as the unknown resistance the current in the two branches will be equal, and the needle of the galvanometer will show *no deflection*.

Ques. What name is given to this method of testing?

Ans. It is called a *zero* method, distinguishing it from *deflection* methods.

Ques. For what kind of resistance is the method adapted?

Ans. Since it is a nil or zero method, it is better adapted to the measurement of non-inductive than of inductive resistances.

Ques. What precaution should be taken with inductive resistances?

Ans. The current must be allowed to flow until it becomes steady to overcome the influence of self-induction.

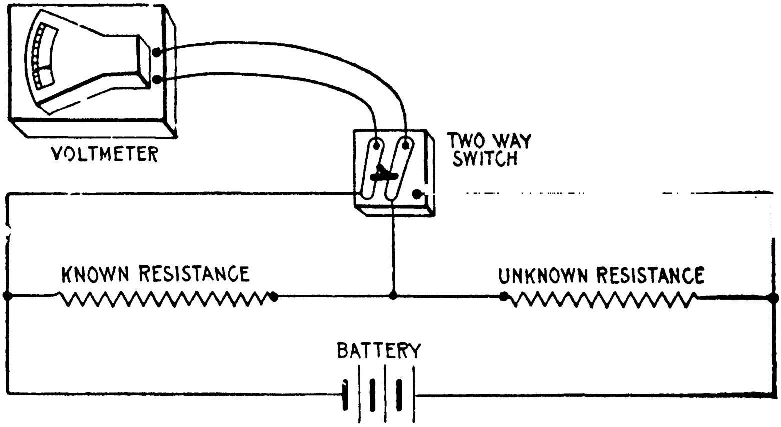


FIG. 1,182.—Drop method of testing resistances. The apparatus is connected as shown and readings taken with volt meter across known and unknown resistance. The unknown resisance is then easily calculated.

Ques. What may be said with respect to the differential galvanometer method?

Ans. With an accurate instrument it is very reliable.

Drop Method.—This is a convenient method, and one which may be used for measuring either high or low resistances with precision. It is used for many practical measurements, and requires only a voltmeter, battery, known resistance and a two way switch.

The instruments are connected as in fig. 1,482, and in making the test, the volt meter is switched into circuit across the known resistance and then across the unknown resistance, readings being taken in each case. The value of the unknown resistance, is then easily calculated from the following proportion:

$$\frac{\text{drop across known resistance}}{\text{drop across unknown resistance}} = \frac{\text{known resistance}}{\text{unknown resistance}}$$

from which

$$\left.\begin{matrix}\text{unknown}\\\text{resistance}\end{matrix}\right\} = \frac{\text{known resistance} \times \text{drop across unknown resistance}}{\text{drop across known resistance}}$$

Ques. What may be substituted for the volt meter?

Ans. A high resistance galvanometer, whose deflections are proportional to the current, the value of the deflections being substituted in the formula.

Ques. What precaution should be taken in making the test?

Ans. The current used should not be strong enough to appreciably heat the resistance, and if the current be not very steady, several readings should be taken of each measurement and the average values used in the formula.

Ques. How are the most accurate results obtained?

Ans. By selecting the known resistance as near as possible to the supposed value of the unknown resistance.

Volt Meter Method.—This is a direct deflection method and consists in determining first the resistance that will deflect the needle through one division of the scale on a given battery current, then with this as a basis for comparison the volt meter is connected across the unknown resistance whose value is easily calculated from the reading.

In making the test, the instruments are connected as in fig. 1,483. The current from battery is first passed through the galvanometer by turning switch as shown.

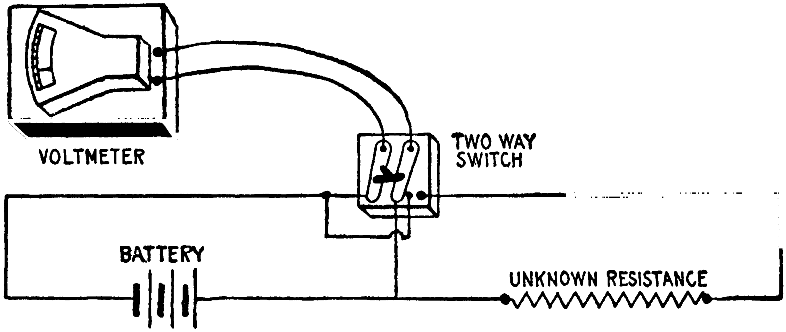


FIG. 1,483.—Volt meter method of testing resistances Knowing the resistance of the volt meter, turn switch to the left and from reading calculate resistance corresponding to one division of the scale. Turn switch to right and multiply reading by resistance required for deflection of one division. This gives resistance of volt meter and unknown resistance; subtracting from this the resistance of volt meter gives value of the unknown resistance.

Assuming the resistance of the instrument to be 8,000 ohms and that the current deflects the needle through 10 divisions of the scale, then for a deflection of one division the resistance is

$$8{,}000 \times 10 = 80{,}000 \text{ ohms.}$$

Accordingly, if, when the switch is moved to the right connecting the volt meter across the unknown resistance, the needle be moved through 6 divisions of the scale, the combined resistance of the volt meter and unknown resistance is

$$80.000 \div 6 = 13.333\tfrac{1}{3} \text{ ohms,}$$

and substracting the resistance of the volt meter, the value of the unknown resistance is

$$13,333\tfrac{1}{3}-8,000=5,333\tfrac{1}{3} \text{ ohms.}$$

Ques. For what kinds of test is the volt meter method best adapted?

Ans. For measuring high resistances, as the insulation of wires, etc.

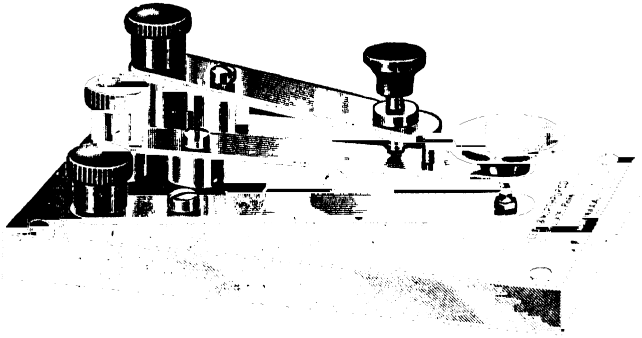


Fig 1,484.—Double contact key It is of especial value in connection with a Wheatstone bridge. When used with the latter it forms a combination battery and galvanometer key. The battery is wired to the top leaves of the key and the galvanometer to the lower leaves. Hence, when operated, the battery circuit will be closed before the galvanometer circuit, as it is desirable to avoid undue disturbance of the needle.

Ques. What may be said with respect to the current used?

Ans. Its voltage should be as high as possible within the limits of the volt meter scale.

Ques. In testing cable insulation what is desirable with respect to volt meter and current?

Ans. A low reading volt meter should be used in connection with a large battery.

Wheatstone Bridge Method.—For accurate measurements of resistance this method is almost universally used.

The so called "Wheatstone" bridge was invented by ***Christie,*** and improperly credited to Wheatstone, who simply applied Christie's invention to the measurement of resistances.

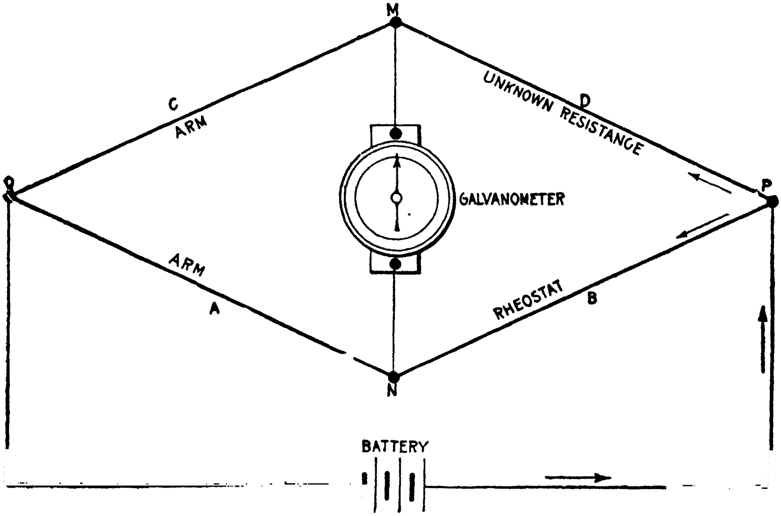


FIG. 1,485.—Diagram showing principle of Wheatstone's bridge. A, B, C and D, are the four members which constitute the bridge. The current from the battery divides at P, part traversing DC, and part traversing BA. The galvanometer connected to M and N, will indicate when the currents are equal in the two branches by giving *no* deflection. This is then a *zero* or *nil method* of testing. The resistances and keys required in testing are shown in fig. 1,489. In the actual instrument, the members A, B, C, and D, are known by the names given in the figure.

This stigma has become so firmly rooted that it will perhaps have to be tolerated.

The bridge consists of a system of conductors as shown in fig. 1,485. The circuit of a constant battery is made to branch at P, into two parts, which re-unite at Q, so that part of the current flows through the point M, the other part through the point N. The four conductors A,B,C,D, are spoken of as the *arms* of the balance or bridge.

It is by the proportion existing between the resistances of these arms that the resistance of one of them can be calculated when the resistances of the other three are known.

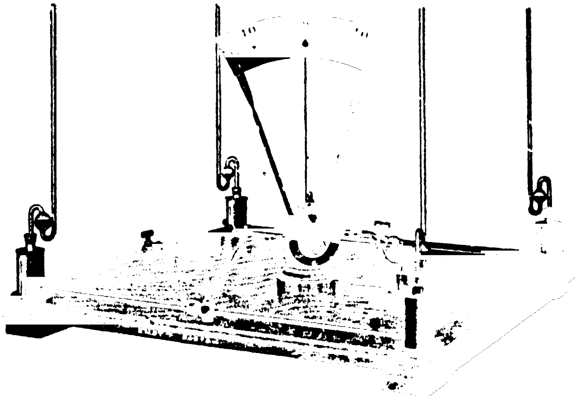


FIG. 1,486 —Knott hydrodynamic Wheatstone bridge for a study of the principles involved by measurements of resistance by the Wheatstone bridge method, using fall of hydraulic pressure as an analogy to electric pressure. On a polished wooden baseboard is mounted a system of tubes connected to form a Wheatstone diagram In the "arms" are reducing valves analogous to resistances Pressures in the various arms are indicated by the manometers. In the "bridge" is a pressure indicator analogous to the galvanometer by connecting to one of the nipples and allowing a flow of water through the apparatus, the fall of pressure through the different arms may readily be noted. By regulating the reducing valves in these arms, a balance may be secured when no indications of pressure can be noted in the "bridge." The pressure in the arms will be noted in the manometer.

When the current which starts from the battery arrives at P, the pressure will have fallen to a certain value. The pressure in the upper branch falls again to M, and continues to fall to Q. The pressure of the lower branch falls to N, and again falls till it reaches the value at Q. Now if N, be the same proportionate distance along the resistances between P and Q, as M, is along the resistances of the upper line between P and Q, the pressure will have fallen at N, to the same value as it has fallen to at M; or, in other words, if the ratio of the resistance C, to the resistance D, be equal to the ratio between the resistance A, and the resistance B, then M and N, will be at equal pressures. To find out if this condition obtain, a sensitive galvanometer is placed in a branch wire between M and N, which will show *no* deflection when M and N, are at equal pressure or when the four resistances of the arms "balance" one another by being in proportion, thus:

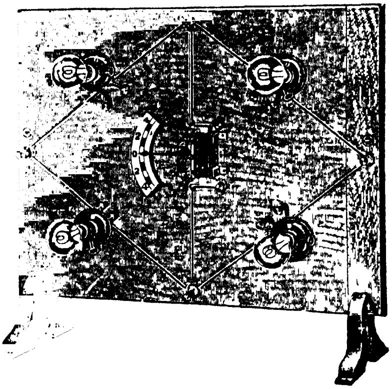


FIG. 1,487.—Knott demonstration Wheatstone bridge for a study of fall of potential and demonstration of the principle of the Wheatstone bridge This apparatus was designed for use on the lecture table, which accounts for its generous proportions Each arm of the bridge has an incandescent lamp inserted in it, so that whether current goes through that arm or not becomes evident instantly A galvanometer is provided as part of the outfit.

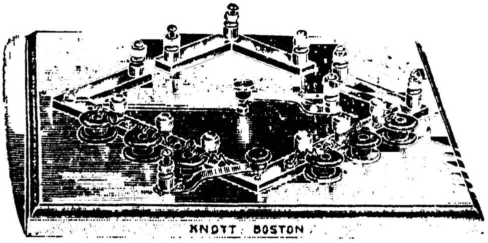


FIG. 1,488 —Knott demonstration Wheatstone bridge, diamond form for practical application of Wheatstone diagram in determining resistance As will be noted from the illustration, all connections and coils are mounted on a base according to the Wheatstone diagram as found in standard text books. In the "ratio arms" are coils of 1, 10 and 100 ohms The "balance arms" are provided with gaps each with non-detachable binding posts, one pair for the "known" and one pair for the "unknown" resistance. Binding posts and a key are provided for the battery and galvanometer circuits.

$$A : C = B : D \ldots\ldots (1)$$

If, then, the value of A, B, and C, be known, D, can be calculated. The proportion (1) is reduced to the following equation before substituting.

$$D = \frac{BC}{A}$$

For instance, if A and C, be, as in fig. 1,489, 10 ohms and 100 ohms respectively, and B be 15 ohms, D will be (15×100) ÷ 10 = 150 ohms.

As constructed, Wheatstone bridges are provided with some resistance coils in the arms A and C, as well as with a complete set in the arm B.

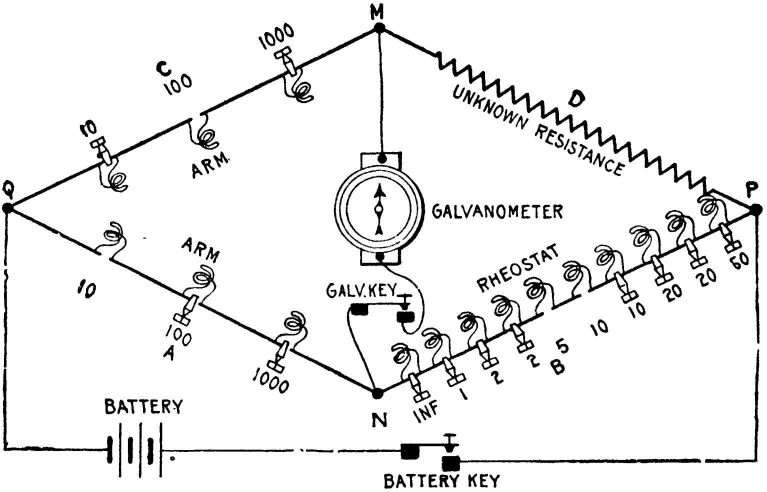


FIG. 1,489.—Diagram showing arms of Wheatstone bridge, resistances and method of connecting galvanometer, battery and unknown resistance.

The advantage of this arrangement is that by adjusting A and C, the ratio between B and D, can be determined, and can, in certain cases, be measured to fractions of an ohm. In fig. 1,489 resistances of 10, 100, and 1,000 ohms are included in the arms A and C.

Ques. Describe the method of testing with the bridge.

Ans. Fig. 1,490 illustrates the general arrangement of resistances to be found in an ordinary bridge. The connections are made as shown. In testing, first *depress* the battery key, then *tap* the galvanometer key. This should be repeated adjusting the resistances till no deflection is obtained. The resistance then in the arm B×(C÷A), will give the value of the unknown resistance.

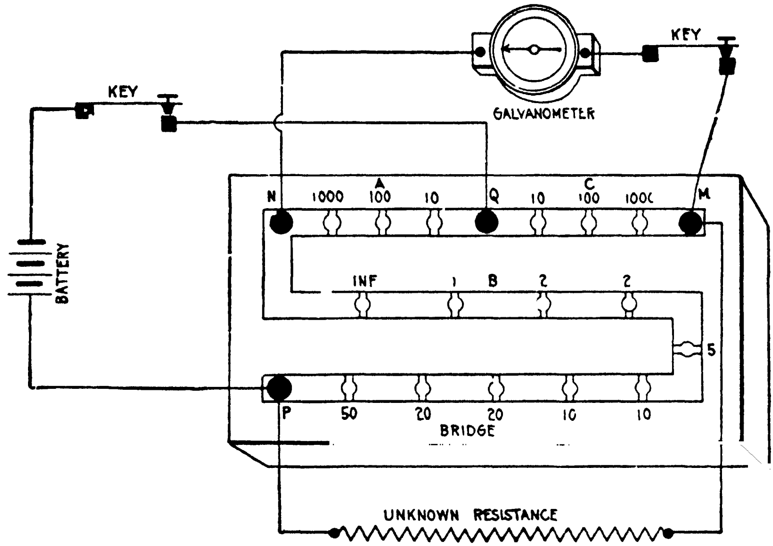


FIG 1,490 —Diagram showing usual arrangement of resistances in arms of Wheatston bridge. *In practice* the bridge is seldom or never made in the lozenge shape of the diagrams, figs 1,485 and 1,489, these being given merely for clearness The resistance box of fig 1,483 is, in itself, a complete "bridge," the appropriate connections being made by screws at various points. The letters in the above diagram correspond with those in figs 1,485 and 1,489, and the three figures should be carefully compared.

Ques. Why should the battery key be depressed before the galvanometer key?

Ans. To avoid the sudden swing of the galvanometer needle, which occurs on closing circuit in consequence of self-induction.

Ques. How is it known whether too much or too little resistance be unplugged?

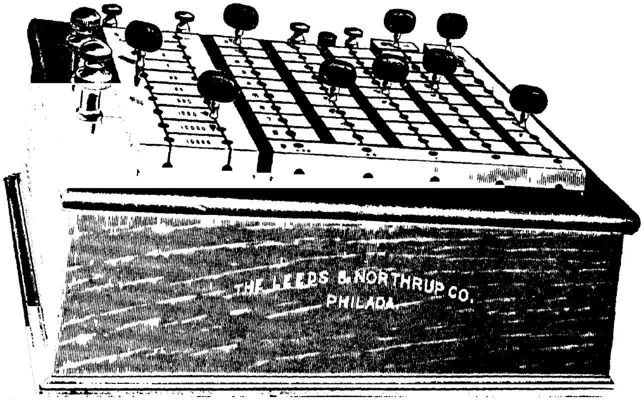


FIG. 1,491.—Standard resistance box and Wheatstone bridge. This pattern is a modification of the Anthony form of bridge. All the resistances are wound upon metal spools. The bridge ratio coils are 1 10, 100, 1,000, 10,000. The rheostat coils are arranged in five rows, of ten coils each. The ordinary decade plan (explained in fig. 1,196) is followed The coils may be joined in series, in multiple, or in any combination of series and multiple. The coils may thus be checked against each other in many combinations. For instance, all the ten ohm coils taken in parallel may be compared with any one ohm coil. The precision of adjustment is said to be $\frac{1}{2}$% for the coils of the tenth ohm series, and $\frac{1}{50}$% for the coils of the rheostat. The ratio coils are certified to be like each other to within $\frac{1}{100}$%. The box is supplied with battery and galvanometer keys of substantial construction.

NOTE.—***Too little attention*** has been given in schools to a thorough understanding of that basic principle, fall of potential, fundamental to Wheatstone bridge work. A student's incomplete understanding of fall of potential makes it difficult for him to understand what he is striving to obtain when he uses a Wheatstone bridge. This incomplete understanding is due, perhaps, to the word of mouth descriptions and the lack of adequate illustrative demonstrative apparatus. To picture for him the actual fall of potential, the Knott demonstration apparatus shown in the accompanying cuts is recommended.

Ans. The galvanometer needle will be deflected to one side for too much resistance, and to the opposite side for too little resistance.

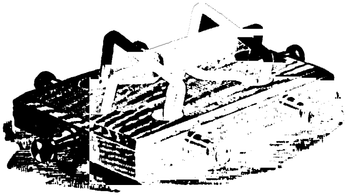


Fig. 1,492.—Pohl commutator. This is equivalent to a two pole double-throw switch. The depressions in the base are filled with mercury into which the contacts dip in closing the circuit.

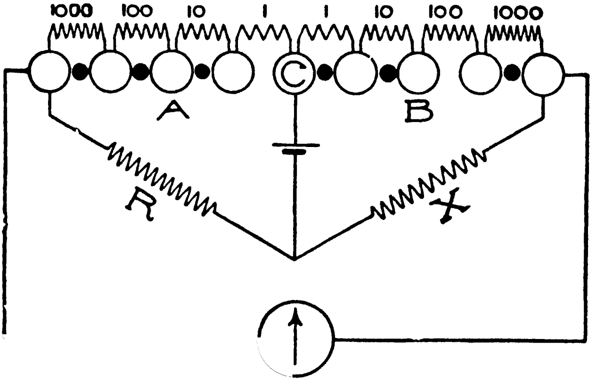


Fig. 1,493.—Ratio coils of Wheatstone bridge. Almost every box intended to serve as a Wheatstone bridge is furnished with a set of coils which forms the arms of proportion or ratio arms of the bridge. There is a choice of several different ways of arranging these coils. The figure shows the simplest arrangement, which is employed in boxes not intended for the highest accuracy. The required ratio, as for instance 1:100 is obtained by withdrawing a plug from each arm A and B. Ratios $\frac{1}{1}$, $\frac{1}{10}$, $\frac{1}{100}$, $\frac{10}{100}$, etc., or $\frac{1,000}{1}$, $\frac{1,000}{10}$, $\frac{1,000}{100}$, $\frac{100}{100}$, etc., are obtainable in this manner. This simple arrangement is open not only to the objection that the contact resistance of the plugs which remain in is always included with the resistance unplugged, but also to all other objections to be urged against the use of many plugs where a few will do. The method has the limitation that it is not possible to reverse the arms of the bridge, that is, to transpose the arms A and B.

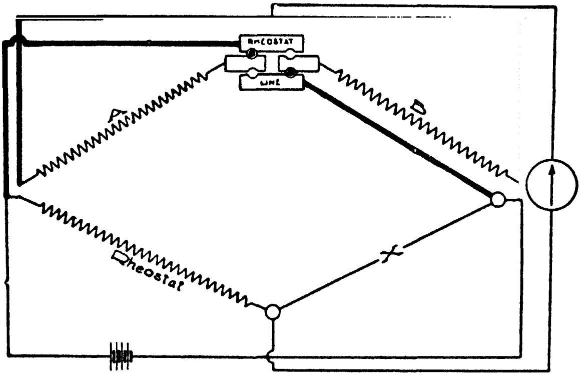


FIG. 1,494.—Method of reversing arms of Wheatstone bridge with reversing blocks. The arrangement shown in the figure is classical, being that used in the English post-office type of Wheatstone bridge. It is open to the objections which apply to the use of several plugs, one of which is withdrawn to obtain the desired resistance.

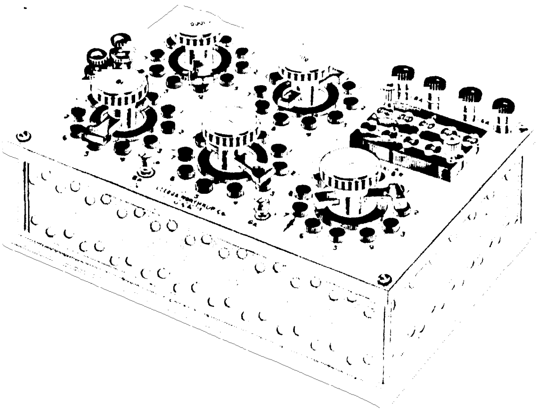
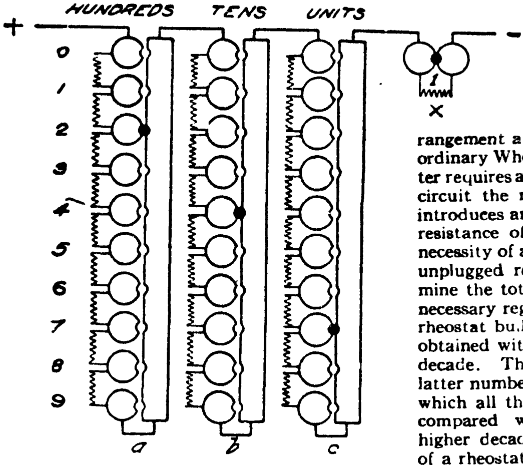
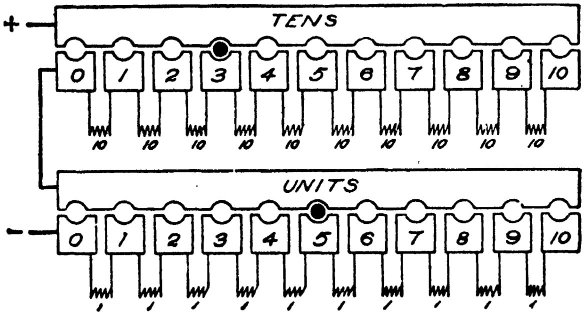


FIG. 1,495.—**Leeds and Northrup dial type Wheatstone bridge. There are five dial decades, 10 × .1 + 9 (1 + 10 + 100 + 1,000) ohms. *Ratio Arms;* ten coils, plug controlled, reversible, 2 each 1, 10, 100, 1,000, 10,000 ohms. *Accuracy:* 1,000, 100, 10 and 1 ohm decades, $\frac{1}{20}$%; 0.1 ohm decade, $\frac{1}{10}$%; ratio coils, $\frac{1}{40}$%. *General:* Large exposed studs; type B Metal spools; individual coil for each switch position; perforated metal box.**



FIGS. 1,496 and 1,497.—Diagrams illustrating the decade plan of combining resistance coils. *In this method* the coils are connected in series and the arrangement avoids the disadvantage of the ordinary Wheatstone bridge in that the latter requires a large number of plugs to short circuit the resistance not in use, which introduces an element of uncertainty as to resistance of the plug contacts and the necessity of adding up the values of all the unplugged resistances in order to determine the total resistance in circuit. The necessary regular succession of values in a rheostat built on the decade plan can be obtained with either nine or ten coils per decade. The chief reason for using the latter number is found in the facility with which all the coils of one decade can be compared with one coil of the next higher decade, thus permitting the coils of a rheostat to be checked among themselves. Thus, the ten 1 ohm coils can be checked with a 10 ohm, the ten 10's with a 100, etc. In some sets the ten coils of a decade can be connected in series or in parallel, and it then becomes an advantage to have ten coils to a decade, since the coils in one decade in parallel equal one of the coils of the next lower decade. When these latter advantages are not required, and especially when dials or sliding switches are used, there is little or no advantage in using more than nine coils per decade, as shown in fig. 1,496. Here all the coils of the set are connected in series so that the circuit is never open. Thus it



is a slight advantage to have permanent connections *a*, *b* and *c*, because all the coils of a decade can be thrown in circuit by simply pulling out a plug, it not being necessary to

Ques. What is the meaning of "Inf.," marked on the bridge?

Ans. It stands for "infinity," because the resistance coil at the point marked infinity is omitted so that adjacent sections of the arm are disconnected when the plug is taken out.

In fact, the air gap interposed by the removal of the plug by no means provides an infinitely great resistance, but is usually called such because it is vastly greater than any of the other resistances of the bridge.

The Decade Plan.—In this method of combining resistance coils, there are 9 or 10 one ohm coils for the units place, 9 or 10 ten ohm coils for the tens place, 9 or 10 one hundred ohm coils for the hundreds place and so on. Each series of coils of the same value is designated a *decade*. The connections are usually made as shown in figs. 1,496 and 1,497.

It is apparent from the figure that any value in any one decade can be obtained by inserting between a bar and a block, only one plug; moreover if several decades be in series, any value up to the limit of the set can be read off directly from the position of the plugs without having to add up the unplugged resistance as in the ordinary arrangement.

Ques. What other advantages are gained with the decade arrangement?

Ans. The single plug used with each decade is never out of use, being either in the zero position or set on some value, and is therefore not easily lost by being laid aside. The use of only one plug in a decade makes it easy to ascertain that the plug

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FIGS. 1,496 and 1,497.—*Text continued.*

insert it again, as would be the case if the *a*. *b* and *c*, connections were not used. Moreover, if any plug make bad contact, its effect is somewhat lessened by having this bad contact shunted by the remaining coils of the decade. Again, there are occasions where violent deflections of a galvanometer are prevented by not having the circuit entirely open when a plug is taken out.

is making good contact as only one block in a row is plugged at a time, the other blocks are not kept under a strain by having plugs forced tightly between them.

This strain on the blocks, which always exists in those sets in which a resistance is thrown in by removing a plug, tends to separate or loosen them and often to warp the hard rubber upon which they are mounted. Another advantage of the decade plan is that it permits obtaining a

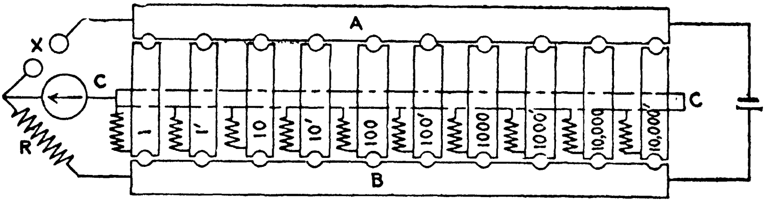
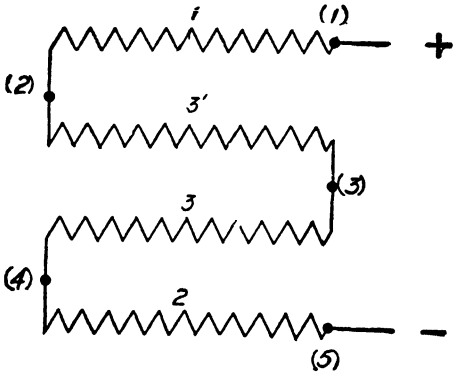
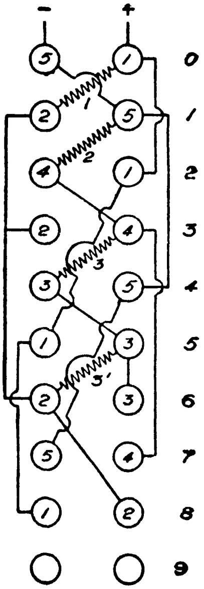


FIG. 1,498.—Two plug arrangement of ratio coils. Each of the ratio coils has one of its terminals connected to a common center which corresponds to the block marked C, in the figure. The other terminal of each coil is connected to an individual block, there being one block for each coil. The bar B, on one side of these blocks is joined to the rheostat and the bar A, on the other side to an X, post. In the ordinary use of this set of ratio coils two plugs only are used. One plug is inserted between the bar A, and one of the blocks, 1, 1', 10, 10', etc., of the central row of blocks. The other plug is inserted between the bar B, and any one of the other blocks of the central row. There are two ratio coils of each value. To obtain an even ratio as 1,000 to 1,000', one plug is inserted between the block 1,000 and the bar A, and the other plug between the 1,000 block and bar B, the ratio arms are reversed; that is, the 1,000 ohm coil is connected to the X, post and the 1,000 ohm coil to the end of the rheostat. When uneven ratios are used, the same ratio can be obtained by four different combinations. To obtain the ratio one to ten, insert a plug between A and 1, and another between B and 10, or between A and 1' and B and 10, and get 1:10, or between A and 1, and B and 10' and get 1:10', or again, between A and 1' and B and 10', and get 1' to 10'. Other ratios are obtained in a similar manner. By using more than two plugs and connecting certain of the coils in parallel combinations, a large number of other ratios may be obtained. This arrangement offers a convenient method of measuring the sensibility of a bridge and galvanometer combination that is frequently applicable. If for instance the one ohm coil be used on either side after a balance has been obtained the one ohm may be shunted with the 1,000 ohm on the same side. This will make a variation of $\frac{1}{10}$ of 1% and the galvanometer deflection may be noted for this variation. Similarly, the 1 ohm may be shunted with the 100 for a variation of 1%, or with the 10,000 for a variation of $\frac{1}{100}$ of 1%. The ten ohm coil may be shunted with the 1,000 for a variation of 1% and with the 10,000 for a variation of $\frac{1}{10}$ of 1%. In the arrangement of ratio coils, errors due to plug contacts are negligible because only two plug contacts enter the circuit, and with an even ratio, it is only the difference in the resistances of the two plug contacts that can affect the result. In measuring any of the ratio coils while in the box it is only necessary to connect to the bar C, and to either the bar A or B, and plug in the coils to be measured.





FIGS. 1,499 and 1,500.—The Leeds and Northrup decade. The object of this arrangement is to reduce the number of coils required. In fig. 1,499, the 1, 3′, 3 and 2 are connected in series. Let the terminals of the 1 ohm and 2 ohm coils be numbered (1), (2), (3), (4) and (5) (fig. 1,499). The current enters at point (1) and leaves the coils at the point (5), traversing 1, 3′, 3, 2 = 9 ohms in all. If this series be multiplied by any factor, *n*, then *n* (1 + 3′ + 3 + 2) = *n* 9 ohms. It will be seen that if the points (1) and (5) be connected, all the coils are short circuited, and the current will traverse zero resistance. If the points (2) and (5) be connected, the 3′, 3 and 2 ohm coils will be short circuited and the current will traverse 1 ohm. By extending the process so as to connect two and only two points at a time it is possible to obtain the regular succession of values *n* (0, 1, 2, 3, 4, 5, 6, 7, 8, 9), the last being obtained when no points are connected. Fig. 1,500 shows Leeds and Northrup's method of connecting these points two at a time with the use of a single plug. The circles in the diagram represent two rows of ten brass blocks each. To the first two blocks at the top of the rows, the points (5) and (1), fig. 1,499, are connected; to the second two, the points (2) and (5) are connected, etc., no points being connected to the last pair of blocks. Hence, if a plug be inserted between blocks 1 and 5, fig. 1,500, the points (1) and (5) of diagram fig. 1,499 are connected, giving the value of 0, if between the blocks 2 and 5 the points (2) and (5) are connected, giving the value 1, and so on. The value 9 is obtainable when the plug is in the last pair of blocks, which have no connection. Fig. 1,498 shows a top view of the blocks of a simple decade constructed upon this plan.

succession of values by means of sliding contacts or dial switches, a method which is becoming deservedly more appreciated

Ques. What is the difference between "plug out" and "plug in" types of resistance box?

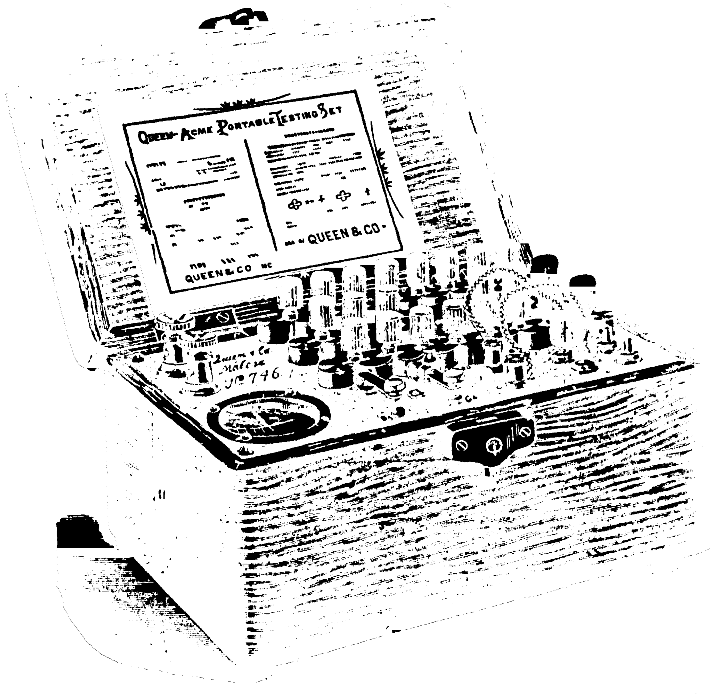


Fig 1,501 —Queen Acme portable testing set *It consists of* a Wheatstone bridge with reversible arms, battery of four dry cells, D Arsonval galvanometer, battery and galvanometer keys There are sixteen resistance coils, having a combined resistance of 11 110 ohms Each bridge arm is provided with three coils of 1 10, 100 ohms, and 10 100, 1 000 ohms respectively The commutator admits of a ratio of 1 to 1 000 on either bridge arm, giving the set a theoretical range from 001 of an ohm to 11 110 000 ohms For resistances above 1,000,000 ohms, the normal battery power must be increased The contact keys are located as shown The battery key has single contact, but the galvanometer key has double contact, depressing it closes the galvanometer circuit, and releasing it short circuits the galvanometer, bringing the latter quickly to rest

Ans. In the plug out type, resistance is put in the circuit by removing plugs, as in fig. 1,489; in the plug in type, resistance is put in the circuit by inserting plugs as in figs. 1,496 and 1,497.

Testing Sets.—For convenience in testing, a combination of the instruments used is put up in a neat and substantial case, and known as a testing set. There are innumerable forms of testing set, a few of which are shown in the accompanying illustrations. The usual combination is a Wheatstone bridge, galvanometer, battery and necessary keys and connections.

Testing sets usually employ the principle of the Wheatstone bridge, because the location of faults is largely a question of resistance or capacity measurement, and translation of the measurement into the corresponding distance to the point at which the ground, cross or open occurs. Fault location, and ordinary field or shop resistance measurement require portability and ruggedness in a set, combined with the best possible sensitivity and accuracy. To meet all the requirements is a complex problem in design, and care and attention to detail in manufacture is no less important from the user's standpoint.

Ques. Describe the operation of the Queen Acme testing set figs. 1,501 and 1,502, in measuring resistance.

Ans. Connect the terminals of the resistance to be measured to the line posts C and D. Place the battery connections on the two upper tips 0 and 1, thus throwing one end of the battery into circuit, which is sufficient until an approximate

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NOTE —***The galvanometer*** is the heart of the testing set, and the purchaser of a set should judge as to the merits of the instrument largely on the basis of ruggedness and sensitivity of the galvanometer.

NOTE.—***Galvanometer shunt.*** In making a measurement with a Wheatstone bridge employing a sensitive galvanometer, the operator, if he has no idea of the magnitude of the "X" resistance, usually starts his measurement with the galvanometer shunted so as to make it very insensitive. As he approaches a balance he reduces the shunting in steps until finally the galvanometer has maximum sensitivity. The shunting enables him to obtain his results with greater certainty and speed.

balance is obtained. Employ the 100 ohm coil in each bridge arm, and place the commutator plugs in the position PQ, or in the position ST. Then remove plugs from the rheostat until

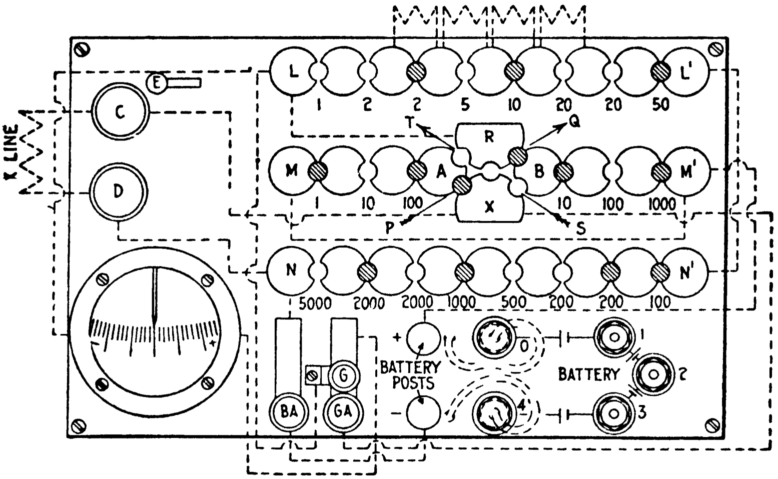


FIG 1,502 —Connections and circuits of Queen Acme portable testing set There are three rows of blocks, LL', MM', NN' LL', is connected to NN' by means of a heavy copper bar, joining L' and N' LL' and NN', constitute the rheostat, from which any resistance from 1 ohm to 11 110 ohms may be obtained by removing the proper plugs The block N, of the rheostat is connected to the lower line post D The upper line post C, is connected to the block X, of the commutator The block C, has no other permanent connection, except key G The block R, of the commutator is connected to the block L, of the rheostat, and has no other connection, excepting by plugs Each half of MM' constitutes a bridge arm, designated A and B, respectively Beginning at the lower line post D, the connections form a continuous circuit through the rheostat, thence through the bridge arm B, thence through the bridge arm A, thence to the upper line post C The commutator serves merely to reverse the bridge arms A and B The battery terminals are connected as shown, the positive terminal directly to the common junction of the two bridge arms, and the negative terminal through the battery key to the rheostat The positive terminal of the galvanometer is connected through the galvanometer key with the block X, and the negative terminal with the block R, of the commutator, or, what is equivalent, with the block L, of the rheostat The commutator blocks A, B, R and X, are connected by plugs as shown When the commutator plugs are in the position PQ, the bridge arm B, is connected to the rheostat and the bridge arm A, is connected to the line, the ratio between the bridge arms ratio being A ÷ B = X ÷ R, but when the plugs are in the position ST, the bridge arms are reversed in position A, being connected with the rheostat and B, with the line, and the bridge arm ratio becomes A ÷ B = R ÷ X The connections of the testing set may be more readily understood from the simplified diagram fig. 1,503.

the value of total resistance employed, or nearly as may be guessed is equal to that of the unknown resistance. Now press the battery key Ba, and holding it down momentarily, press the galvanometer key Ga. If the galvanometer needle swing to the right toward the symbol + the resistance employed in the rheostat is too high, and must be reduced. If the needle swing to the left toward −, the resistance employed is too low and must be increased. By altering the resistance of the rheostat accordingly, a value will soon be found, which when varied slightly either way, will reverse the deflection of the galvanometer needle. Now remove the battery connection from tip 1, and place it on the tip 4, thus throwing the whole battery into circuit. Then press the keys again as before, first the battery key, then the galvanometer key. This will increase the deflection of the galvanometer needle for the same variation in the rheostat, thus enabling the making of a more accurate adjustment. The measurement thus made will be the

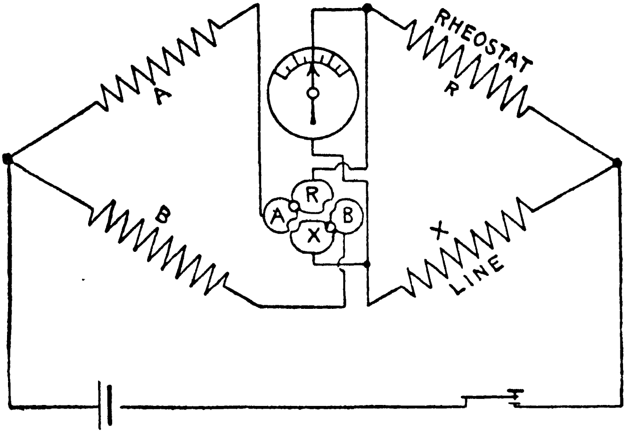


FIG. 1,503.—Simplified diagram showing connections of Queen Acme portable testing set.

best result that can be obtained with bridge arms of equal value, but by selecting more suitable values of the two arms from the following table of bridge ratios a much higher degree of accuracy may be obtained.

Table Showing the Best Values of Bridge Arms for Measuring any Desired Resistance

Value of Resistance being measured	Best values of		Position of Commutator Plugs as shown in fig. 582
	A =	B =	
Below 1.5 ohms..............	1	1,000	PQ
Between 1.5 and 11 ohms..........	1	100	PQ
" 11 and 78 ohms...........	10	100	PQ
" 78 and 1,100 ohms	100	1,000	PQ
" 1,100 and 6,100 ohms......	100	100	PQ or ST
" 6,100 and 110,000 ohms....	1,000	100	ST
" 110,000 and 1,110,000 ohms.	1,000	10	ST
" 1,110,000 and 11,110,000 ohms	1,000	1	ST

Ques. In testing with the Queen Acme set how should the plugs be placed in the commutator?

Ans. Always make the arm A, the smaller except when the two arms are of equal value.

Ques. If the resistance being measured be higher than 6,100 ohms, or lower than 1,100 ohms, how should the commutator plugs be placed?

Ans. If higher than 6,100 ohms, they should be placed in the position ST; if lower than 1,100 ohms, in position PQ.

When the plugs are placed in the ST, position, the unknown resistance is found by dividing the value of the larger bridge arm by that of the smaller, and multiplying the total employed resistance in the rheostat by the quotient. When the plugs are placed in the PQ, position, the employed resistance in the rheostat is divided by the quotient.

Direct Deflection Method with Queen Acme Set.—To

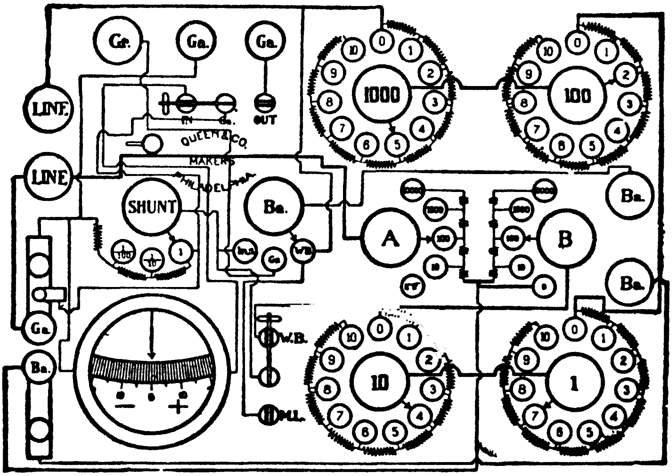


Fig. 1,504.—Diagram of the Queen dial decade portable testing set. *Its dimensions are* 9½" long, 7" wide, and 7" deep, and weighs 11½ pounds. The resistances are arranged upon the dial decade plan. being placed in circuit by means of a rotating switch contact. The switches are so constructed that they may be turned in either direction, thereby permitting them to be turned quickly from the highest resistance in any dial to the lowest resistance in the same dial. This arrangement avoids the necessity of turning back through all the remaining resistances in any particular group of coils and is of value in locating swinging crosses or conditions of momentary balances. The connections for the various tests are made by the manipulation of one small knife switch (W.B.—M.L.) and the switch Ba.; these are plainly lettered, thus avoiding the necessity of referring to a diagram of connections. In construction, the dial switches are made up of eight laminations of No. 28 B. & S. phosphor bronze, and the form is such as to prevent wearing grooves on the top of the contact studs. In this instrument the electrical circuits are soldered throughout excepting the switch contact whose resistance is negligible. The resistances are wound with manganin. The battery comprises six cells sub-divided which are easily replaceable. The galvanometer is the same as in the Queen Acme set, but has the addition of an Ayrton shunt, which is useful in making insulation measurements. The necessary keys, binding posts, and switches are provided so as to facilitate the use of the instrument for the various measurements that can be made with it.

measure for instance, insulation resistance by direct deflection connect a known high resistance, say 100,000 ohms between the line post C (fig. 1,502), and the positive battery post. Remove all plugs from the commutator, and place all plugs in the rheostat, as any employed resistance in the rheostat will be in circuit with the galvanometer and the battery. Place the battery connection so as to throw only one cell into circuit. Now press the keys and obtain a deflection of the galvanometer needle.

For example assume that the needle to be deflected about 8 divisions of the scale. Since this deflection is due to the current from one cell passing

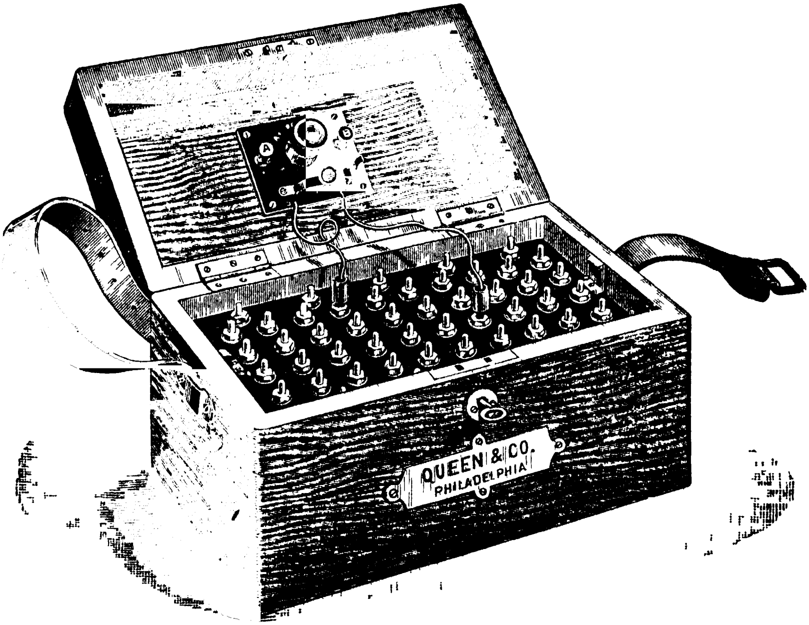


Fig 1,505—Queen portable silver chloride testing battery. The silver chloride cell has the advantage of long life, light weight, and compactness. The pressure of each cell when new is 8 volt.

through a resistance of 100,000 ohms, then 100,000×8 = .8 megohm represents the resistance through which one cell will produce a deflection of one division on the scale. Hence, .8 megohm is the constant of the galvanometer.

Now, replace the known high resistance (100,000 ohms) by the unknown resistance (for instance such as a cable) the value of which is to be determined. Add enough cells to produce as large a deflection of the needle as possible. Assume that 75 cells give a deflection of 1.5 scale division. Then, the galvanometer constant multiplied by the number of cells and the product divided by the deflection will give the insulation resistance of the cable; or

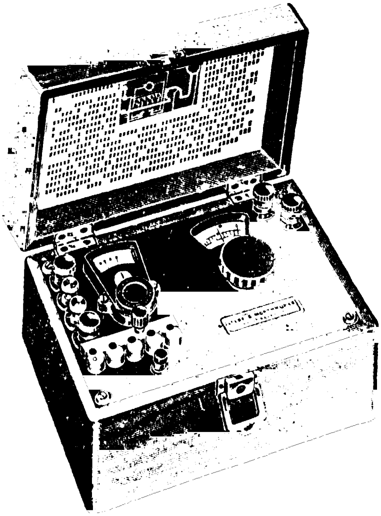


Fig. 1,506.—Leeds and Northrup ohm meter. It *consists essentially of* a slide wire Wheatstone bridge with the scale divided to read in per cent of a fixed resistance value. A galvanometer is mounted on the containing case of each battery and galvanometer keys are provided. These ohm meters, being slide wire bridges, the greatest accuracy is at the center of the scale. Fixed coils of 1, 10, 100, 1,000 and 10,000 ohms are contained in the instrument with a plug arrangement allowing any one to be used. When a balance is obtained the actual resistance is determined by multiplying the dial reading by the value of the fixed coil in use. This amounts simply to shifting the decimal point. For instance, if the 100 ohm coil were being used and the pointer were at .875, the resistance would be 87.5 ohms Accuracy 1% over the range 3 ohm to 30,000 ohms.

$$.8 \text{ megohm} \times 75 \text{ cells} = 60.0; \text{ and}$$
$$60.0 \div 1.5 = 40 \text{ megohms}$$

as the resistance of the cable.

Fall of Potential Method with Queen Acme Set.—To compare electromotive forces by this method, place the battery connections (fig. 1,502), so as to throw into circuit all the cells, taking care not to reverse them by crossing the battery cords. Plug the commutator as shown in fig. 1,507, and remove 1,000 ohms from bridge arm B. Place all plugs in arm A.

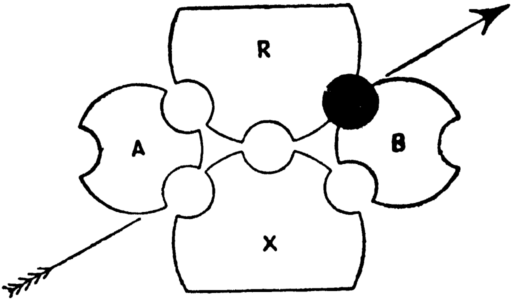


FIG. 1,507.—Commutator plug setting for comparing electromotive forces by the fall of potential method with Queen acme set.

From the rheostat unplug 5,000 ohms.

Then connect one of the cells being tested, with its positive terminal to the + battery post and its negative terminal to the line post C.

When the keys are pressed, the galvanometer needle will swing either to the right or to the left. If it swing toward +, reduce the resistance in the rheostat; if it swing toward −, add resistance to the rheostat. When a value is found wherein a variation of an ohm either way reverses the deflection, add to this value the resistance unplugged in arm B, and divide the sum by the resistance in arm B. The result gives the ratio between the voltages of the testing set, battery and cell being tested, respectively.

The division is decimal and may be readily accomplished by merely pointing off as many places as there are ciphers in the resistance employed from arm B. This operation repeated with any number of different cells, will give their voltages in terms of the voltage of the testing set battery, and from these ratios their relative values may be readily obtained.

If the testing set battery be replaced by a standard cell, the first measurement gives at once the voltage of the cell tested.

If the voltage of the cell or battery being tested exceed that of the testing set battery, reverse the position of the two batteries, and the subsequent operations, as outlined above, will give the desired results.

How to Check a Volt Meter with the Queen Acme Set.— In using a set as in fig. 1,501, first remove about 10,000 ohms from the rheostat, plug the commutator as shown in fig. 1,507, remove 100 ohms from the arm B, of the bridge, and connect a standard cell with the positive terminal to the + battery post and the negative terminal to the line post C. Then, connect the circuit to the battery posts of the testing set the positive lead to the + post and the negative lead to the − post. Now, press both keys and note the direction of the deflection of the galvanometer needle. If it move toward +, the rheostat resistance is too high; if toward −, too low.

Change the rheostat resistance accordingly until the balance attained is such that a very slight variation of the rheostat resistance one way or the other will reverse the galvanometer deflection. To find the pressure on the circuit, add 100 to rheostat resistance and point off two places. Multiply this value by the voltage and the product will be the desired voltage.

If the voltage of the standard cell be exactly one volt, the total employed resistance represents the voltage on the circuit.

For instance, in making a measurement on a 110 volt circuit, assume that the employing of 7,840 ohms rheostat resistance produces balance, and that increasing or decreasing this resistance by two ohms, reverses the galvanometer deflection. This indicates that the setting 7,840 is uncertain, about $\frac{1}{40}$ of 1 per cent. Since the rheostat coils are adjusted to an accuracy of only $\frac{1}{5}$ of 1 per cent , that will be about the accuracy of the measurement.

If the pressure of the standard cell be 1.018 volts, then 7,840+100= 7,940. Pointing off two places, gives 79.40, which multiplied by 1.018 gives 80.82 for the voltage on the circuit.

To Measure Internal Resistance of Cell with Queen Acme Set.—First compare its voltage on open circuit with the pressure of the testing set battery. Then, shunt the cell with a known resistance, about 100 ohms, and again measure its terminal voltage. The difference between the two values thus obtained, divided by the value of the shunt resistance, will

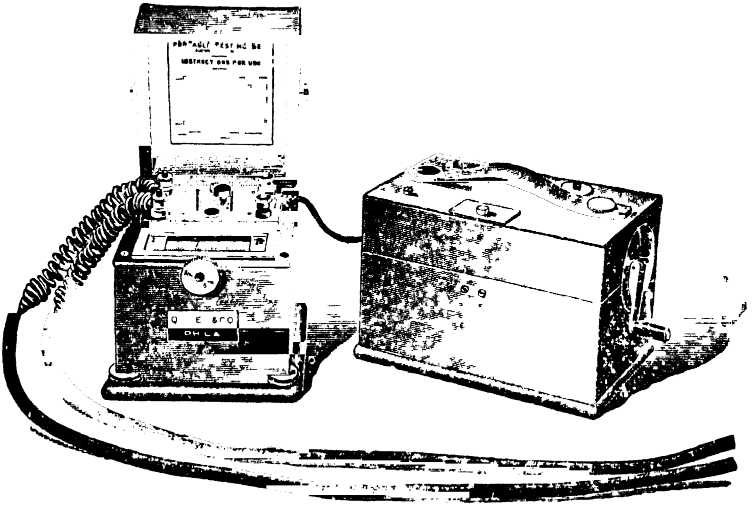


FIG. 1,508 —Evershed portable ohm meter set This testing set consists of a direct reading ohm meter which indicates by direct reading the value of the resistance being tested, also a portable hand dynamo which provides at any required pressure the current necessary to make the test. It is adapted to the needs of supply stations, wiring contractors and dynamo builders. It is also useful in testing the insulation of underground and aerial cables, and is designed so that it can be used by ordinary workmen who are not experienced in handling delicate instruments and who, by its use, are able to obtain accurate results The dynamo is wound for 100, 200, 500, or 1,000 volts, and is fitted with spring drum inside the case on which is coiled a twin flexible cord provided with a connector adapted for clamping under the ohm meter terminals.

give the value of the current. To find the internal resistance, multiply the value of the shunt resistance by the ratio between the first and second measured values.

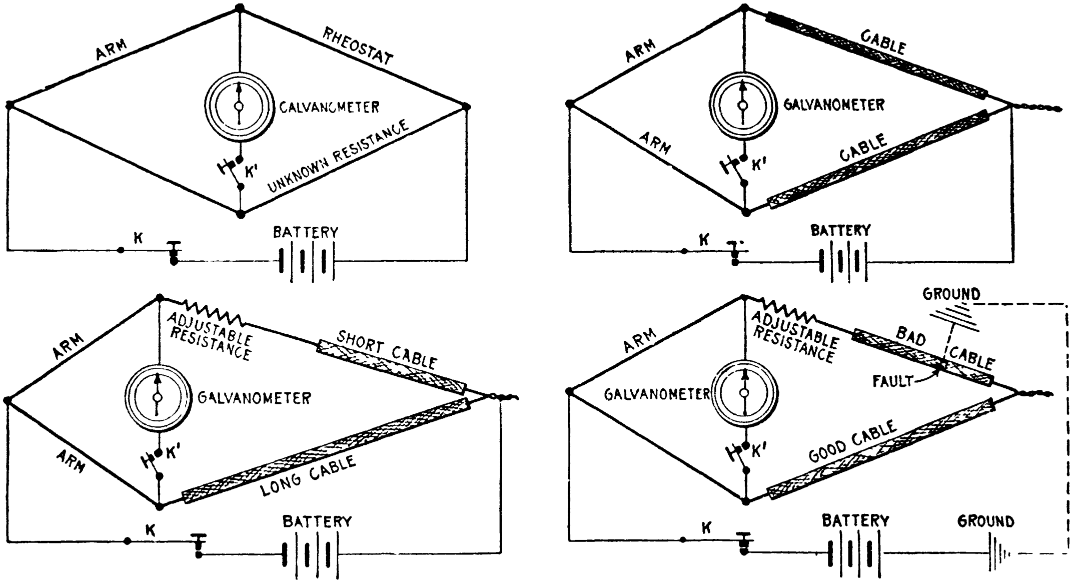
For instance, assume that the open circuit voltage of the cell being tested as compared with the voltage of the testing set battery is .212 of the latter, and that when it is shunted with a resistance of 1,000 ohms. its terminal voltage is .179. Then, the total resistance is to the 1,000 ohms shunt resistance as .212 is to .179 or $\frac{.212}{.179}\times 1{,}000 = 1{,}184$, from which deducting the 1,000 ohms shunt resistance, gives 184 ohms as the internal resistance of the cell.

Ammeter Test with Queen Acme Set.—Connect a low resistance in series with the ammeter and run leads from it to the testing set, the positive lead to the + battery post and the negative lead to the line post C, (fig. 1,502). Insert a standard cell between the battery posts, with positive terminal to + battery post, and negative terminal to − battery post. Plug commutator as shown in fig. 1,507. Remove 10,000 ohms from rheostat, and 100 ohms from bridge arm B. Determine a balance in the usual way by changing the value of the resistance in the rheostat. This operation will balance the difference of pressure at the terminals of the shunt resistance against the standard cell, and its value is equal to

$$\frac{1.40\times 100}{R+100} = \frac{140}{R+100}$$

To determine the current flowing, divide the value of the difference of pressure thus obtained by the value of the shunt resistance.

Loop Test.—This is a method of locating a fault in a telegraph or telephone circuit when there is a good wire running



Figs 1,509 to 1,512.—Diagrams illustrating loop testing To properly understand the Murray or Varley loop tests, consider a Wheatstone bridge (fig 1,509) the arms of which are equal. In loop testing, the rheostat is replaced by a length of cable and the unknown resistance also by a length of cable, as in fig. 1,510, both being similar in resistance per foot. If both lengths be the same, their resistances are the same and the bridge balances. Now shorten one cable and add resistance in series with it until the bridge again balances as in fig 1,511. The added resistance equals that of the piece cut off. Hence, if the resistance per foot be known, the length of the shorter piece can be easily calculated. In the Murray and Varley tests, the battery circuit is by ground connections instead of by wire. In the Murray loop the arrangement is similar to fig. 1,510, the battery circuit being completed by ground connection through fault in defective cable. Fig. 1,512 shows the general arrangement of the Varley loop.

parallel with the defective one. In the process, the good and bad wires are joined at their distant ends and one terminal of the battery is connected to a Wheatstone bridge, while the other terminal is grounded. There are several ways of making loop tests as by:

1. The Murray loop;
2. The Varley loop.

These tests are the ones most frequently used. Some other loop methods and various modifications of these tests have been worked out to meet specific requirements.

The Murray Loop.—In this test only one of the two regular bridge arms is used, the other being replaced by the rheostat giving an arm of large adjustment.

NOTE —*Fault location.*—The fundamental principles of fault location are quite simple and are easily understood In many cases their application is equally simple In other cases, the conditions are complicated by a network of wires, by peculiarities of the faults and other causes However, the very great majority of faults can be located successfully by experienced testers with proper apparatus To insure success, the tester should have a clear conception of the fundamental principles and an accurate knowledge of line conditons This knowledge and careful practice with reliable testing apparatus will soon give one the skill, judgment and confidence which will enable one to locate the most puzzling faults.

NOTE —*Grounds and crosses* in land lines and short submarine cables are practically all located by the so called methods These are particular cases of the Wheatstone bridge and must all satisfy the Wheatstone bridge conditions When four resistances are grouped and a battery and galvanometer form part of the circuit as shown, the combination is called a Wheatstone bridge The resistances are to be understood individually as the total resistance from a battery connection to the next galvanometer connection The resistances are called the bridge arms. It is important to remember this as mistakes are frequently made due to the unintentional introduction of lead or contact resistances into one or more of the bridge arms, which are overlooked in the subsequent calculations The conditions for a balance will be precisely the same if the positions of the galvanometer and battery be interchanged.

NOTE.—*The Murray loop.* The loop tests are so called because the faulty wire is always connected at its distant end with a good wire and the two in combination make the loop. The loop is divided into two parts by the fault. In the Murray loop arrangement, these two parts of the loop are two arms of the Wheatstone bridge, the other two arms of which are made up in the testing apparatus.

The connections are shown in fig. 1,513. In making the test, close key and note the deflection of the needle due to pressure of chemical action at fault, if any. This is called the *false zero.*

Now apply the positive or negative pole of the battery by depressing the battery key, and balance to the false zero previously obtained by varying the resistance in arms A or R. Then by Wheatstone bridge formula: $RX = AY$, and $L = X + Y$; $Y = L - X$, whence

$$X = \frac{A}{R+A} L \qquad Y = \frac{R}{R+A} L$$

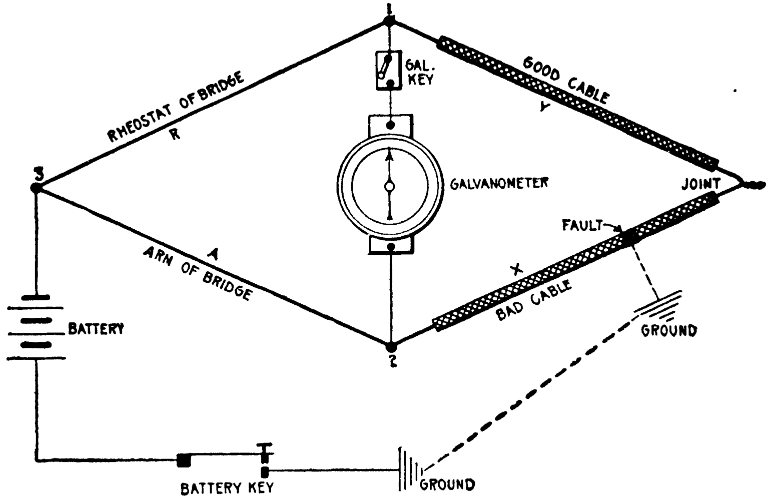


FIG. 1,513.—The Murray loop test. The apparatus is connected as in the figure. The rheostat of the bridge is used in place of the second arm to permit large adjustment. X and Y, are the resistances of the cable between the fault and the points 1 and 2 respectively.

Ques. How may the distance from 2, to the fault be determined in knots or miles?

Ans. Divide Y, by resistance per knot or mile.

The Varley Loop.—This is a method of locating a cross or ground in a telephone or telegraph line or other cable by using a Wheatstone bridge in a loop formed of a good wire and the faulty wire joined at their distant ends. One terminal of the battery is grounded and the other connected to a point on the bridge at the junction of the ratio arms. The rheostat arm then includes the resistance of the rheostat plus the resistance of the fault, while the unknown arm includes the resistance of the good wire plus the resistance of the bad wire beyond the fault. When the bridge is balanced, the unknown resistances may be readily determined by a simple equation.

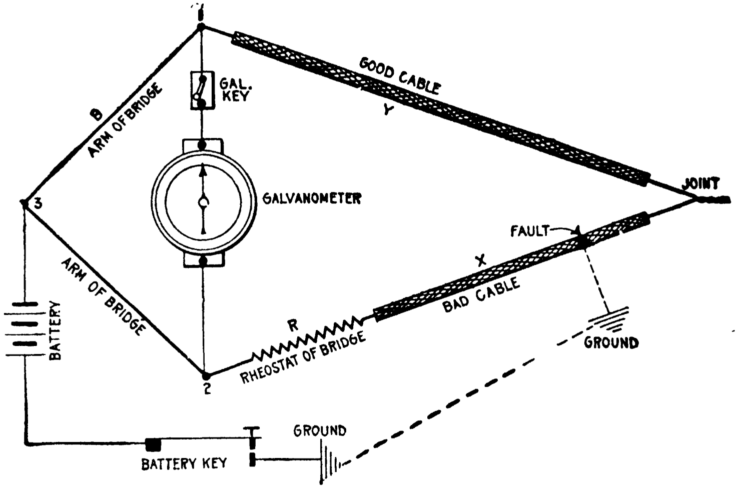


FIG. 1,514.—The Varley loop test. The diagram shows the various connections. **X and Y are** the resistances of the cable between the fault and the points 1 and 2 **respectively. L, is the** resistance of the good and bad cable or X + Y.

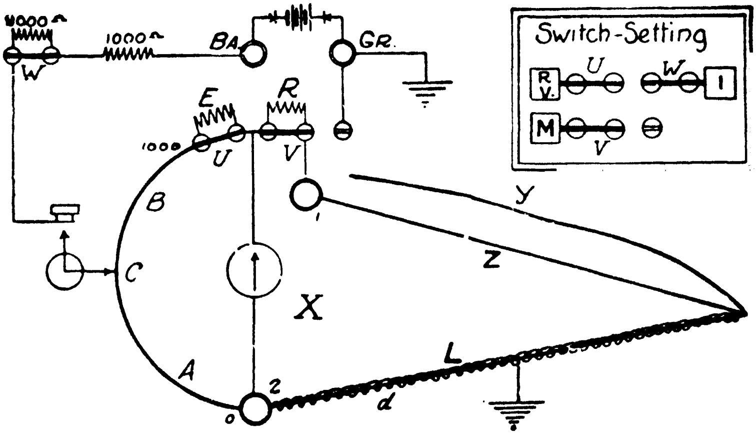
In making the Varley loop test, the resistance of looped cable or conductors is measured, and then connected as in fig. 1,514. Close the battery key and adjust R, for balance.

When earth current is present, the best results are obtained when the fault is cleared by the negative pole, and just before it begins to polarize. If X, be the resistance from 2, to the fault, then

$$X = \frac{L-R}{2}$$

also, X, divided by the resistance of the cable or conductor per knot or mile gives the distance of fault in knots, or miles.

When the resistance of the good wire used to form a loop with the defective wire, together with that portion of the defective wire from the joint to the fault, is less than the resistance of the defective wire from the testing station to the fault, the resistance R, must be inserted between point 1, and the good conductor, the defective wire being connected directly to point. The formula in this case is

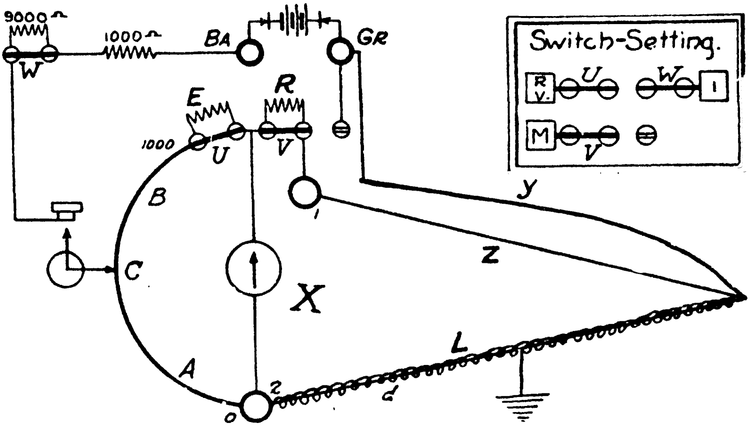


FIGS. 1,515 and 1,516.—Special loop test with Leeds and Northrup fault finder. For the first measurement connect the faulty wire to 2, either of the good wires, as Z, to 1, the post Gr. to ground, and short circuit the coils R, and E, by closing switches U, and V, as in the figures. Balance in the usual way and call the dial reading A. For the second measurement, connect the post Gr. (disconnected from ground), to the other good wire y, as shown in figs. 1,517 and 1,518, and get another balance; call this reading A′. The distance d, to the fault is determined from the simple formula d = AL. ÷ A′, where L, is the length of the cable or faulty wire.

$$X = \frac{L+R}{2}$$

Special Loop.—This method may be used to advantage where the length of the cable or faulty wire only is known and where there are two other wires which may be used to complete the loop. It is not necessary that the resistance of the faulty wire and the length and resistance of the other wires be known. Figs. 1,515 to 1,518 show the connections and method of testing.

Example.—All the wires in a cable 10,852 ft. long were found to be grounded so that none of them could be used as good wires. Two wires were selected out of another cable going to the same place by a different route and securely joined to one of the grounded wires at the distant end. This grounded wire and one of the good ones were connected as shown in figs. 1,515 and 1,516 and the reading A, was found to be 307. Connections were then made as shown in figs. 1,517 and 1,518 and A, was found to be 610. What is the value of d?



FIGS. 1,517 and 1,518.—Special loop test as made with the Leeds and Northrup fault finder. Diagram showing connections for the second measurement. The special loop test may be used to advantage where the length of the cable or faulty wire only is known, and where there are two other wires which may be used to complete the loop. To use an outside battery, connect one pole to Ba, and ground the other. The pressure of this battery must never exceed 110 volts; if it be over 25 volts, see that switch W, is open.

According to formula

$$d = \frac{AL}{A} = \frac{307 \times 10{,}853}{610} = 5{,}461 \text{ ft.}$$

Directions for Operating Leeds and Northrup (Type T) Testing Set.—The following instructions will be found helpful in the use of this set, which is designed specially for locating faults in telephone, telegraph and other electrical transmission lines; also, for any measurements within ordinary Wheatstone bridge range.

Resistance Measurements.—Connect unknown resistance to posts X1 and X2, and place the switch at the back of the set in the position marked RESISTANCE. The internal battery is connected by placing the small

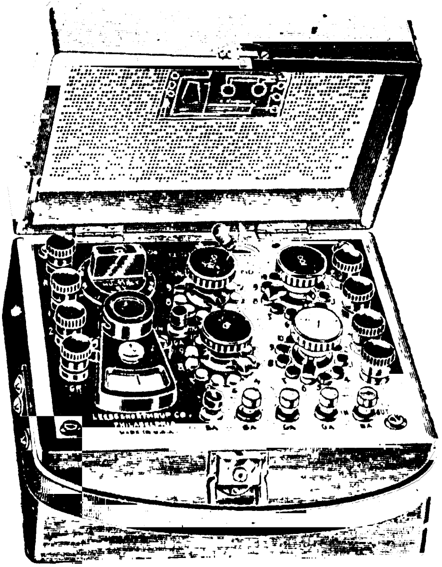


FIG. 1,519.—Leeds and Northrup type T, testing set. ***It is provided with*** the necessary connections for making resistance measurements, and for locating faults by the Murray and Varley loop methods. The addition of a simple buzzer and telephone receiver permits the location of opens as well a single three-way switch, of the type used on telephone switchboards makes possible, with a single motion, immediate connections for resistance, or Murray loop, or Varley loop tests. The switch replaces the two single pole, double throw switches ordinarily used on testing sets. Provision is made for connection of an external battery and galvanometer in the relatively few instances where this may be necessary; and, without changing connections, either internal or external battery or galvanometer may be used. Protective resistances in both internal and external battery circuits guard against burn-outs or overheating of the adjusted coils in the set.

switch in the front of the set in the position marked IN. The internal galvanometer is connected by placing the small switch near the galvanometer in the position marked IN. Select the required ratio on the ratio dial and vary the rheostat dials until a balance is obtained.

The best ratio setting for various resistances is shown in the following table:

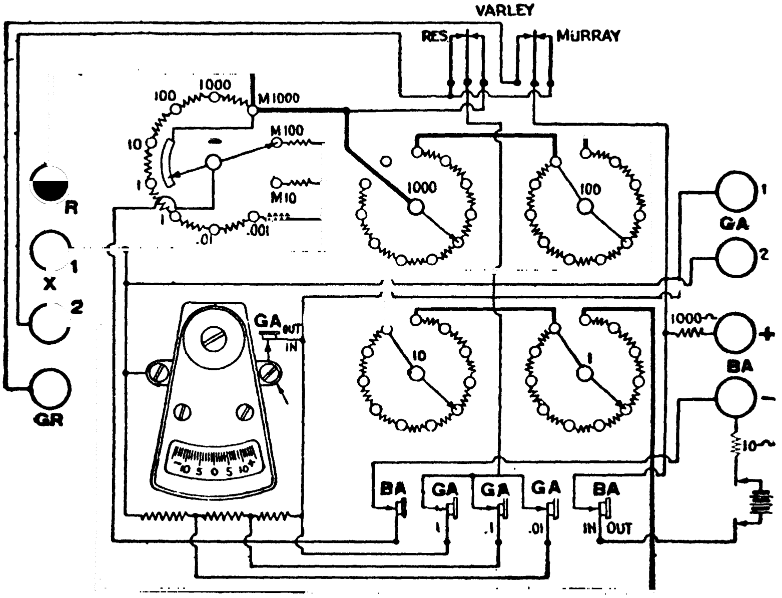


FIG. 1,520.—Connection diagram for making resistance measurement with Leeds and Northrup type T, testing set.

Unknown resistance	**Ratio dial setting**
Below 10 ohms	.001
10 ohms to 100 ohms	.01
100 ohms to 1,000 ohms	.1
1,000 ohms to 10,000 ohms	1.
10,000 ohms to 100,000 ohms	10.
100,000 ohms to 1,000,000 ohms	100.
1,000,000 ohms to 10,000,000 ohms	1000.

The resistance under test is determined from the following formula:

$$X = AR$$

Where X = resistance under test.....................(1)
A = ratio dial setting
R = rheostat setting

Murray Loop Test.—In testing for fault location in cables in the case of a ground, join the faulty and good wires at the distant end of the cable. Connect the faulty wire to X1, as in fig. 1,521 and the good wire to X2. Measure total resistance of the loop and call this r.

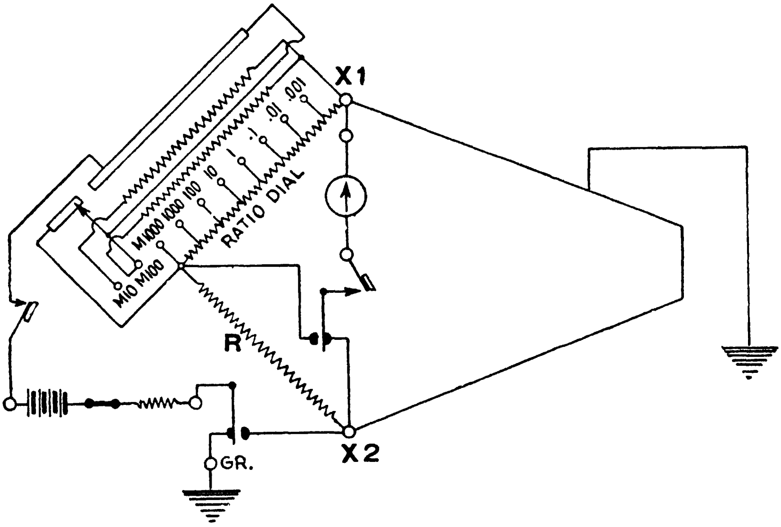


FIG. 1,521.—Connections for Murray loop test.

Connect post Gr, to ground, or if the fault be a cross, connect one of the crossed wires to the Gr, post and at the distant end of the cable join the other crossed wire to a wire that is known to be good. Set ratio switch on M1,000, which places 1,000 ohms in circuit for the bridge arm or A, in the formula. Place the switch at the back of the set in the position marked "Murray." Vary rheostat until a balance is obtained.

If a satisfactory balance can not be obtained with ratio switch set at M1,000, then set for M100 or M10.

Letting r = resistance of loop
a = resistance to fault
R = rheostat reading
A = ratio dial setting

Then
$$a=\frac{Ar}{A+R}\dots\dots\dots\dots(2)$$

If L = length of one of the two wires which are assumed equal since a and r are proportional to the lengths, the distance to the fault becomes

$$d=\frac{2LA}{A+R}\dots\dots\dots\dots(3)$$

If a balance can not be obtained after using all settings down to and including M10, it indicates that the fault is at a point of less than $\frac{1}{1,000}r$ from X1. In such cases locations can be made to $\frac{1}{11,000}r$ as follows:

With connections made as before set the ratio dial on the point marked .001 and use the formula

$$a=\frac{r}{R+1,000} \quad \text{or} \quad d=\frac{2L}{R+1,000}$$

In most cases a check test can be applied by connecting the faulty wire to X2 and the good one to X1, and then varying the rheostat until a balance is obtained. Letting A′ and R′ = new values of A and R,

$$\text{Then}\quad a'=\frac{R'r}{A'+R'}\dots(4) \qquad \text{and} \qquad d'=\frac{2LR'}{A'+R'}\dots\dots\dots\dots(5)$$

If the tests be made on a loop of wire, of which the total length only is known, then this length must be substituted for L, and the 2, removed from the numerators of the above formulæ. One end of the loop should be tagged, and when this end is connected to X1, formula (3) will give the distance to the fault from that end, and formula (5) will give its distance from X2, when the tagged end is connected to that post. When dealing with faults of high resistance 50 or more cells of battery may have to be used.

Example.—The total resistance of a loop, one wire of which was faulty, was found to be 290 ohms. With ratio dial set at M1,000 a balance was obtained with 1,900 in the rheostat. Using formula (2) the resistance to the fault from post X1 is

$$a = \frac{1{,}000 \times 290}{1{,}000 + 1{,}900} = 100 \text{ ohms}$$

In the above example the length of one of the two wires is 8,995 feet. The distance to the fault from post X2 using formula (3), is

$$d = \frac{2\,(8{,}995 \times 1{,}000)}{1{,}000 + 1{,}900} = 6{,}203.4 \text{ ft.}$$

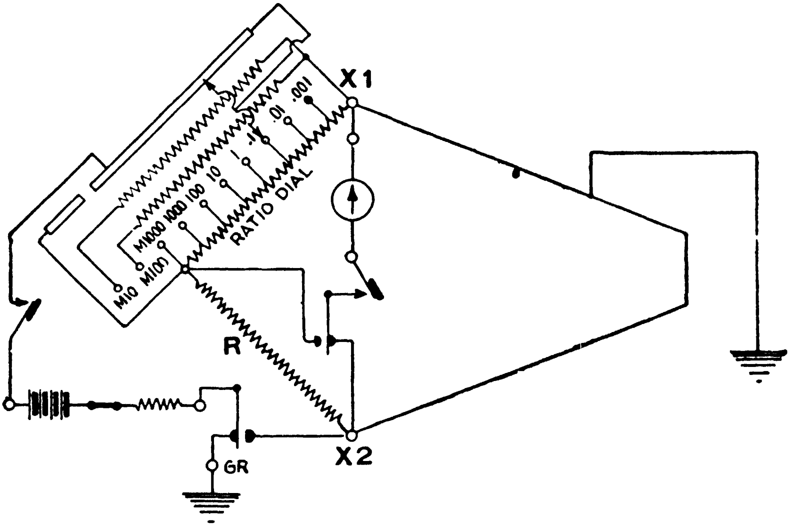


FIG. 1,522—Connections for Varley loop test.

The circuit in fig. 1,521 consists of No. 22 B. & S. copper wire which has a resistance of .01612 ohm per foot The results obtained by formulae (2) and (3) should check, or 6,203.4 feet the distance to the fault by (3) multiplied by .01612 equals 100 ohms, or the resistance to the fault by (2).

Varley Loop Test.—In testing for fault location in cables, in the case of a ground join the faulty and good wires at the distant end of the cable; connect the faulty wire to X2, and the good wire to X1. Measure the total resistance of the loop and call this r. Connect post Gr, to ground. Or if the fault be a cross, connect one of the crossed wires to the Gr, post and at the distant end of the cable join the other crossed wire to a wire that is known to be good. By placing the ratio dial switch on .1, .01, or .001 a ratio of 1 : 10, 1 : 100 or 1: 1000 is obtained. If r, be over 100 ohms, use .1; if less than 100 ohms, use .01. Place the switch at the back of the set in the position marked VARLEY. Vary the rheostat until a balance is obtained.

r = total resistance of loop
a = resistance to the fault
A = ratio dial reading
R = rheostat reading

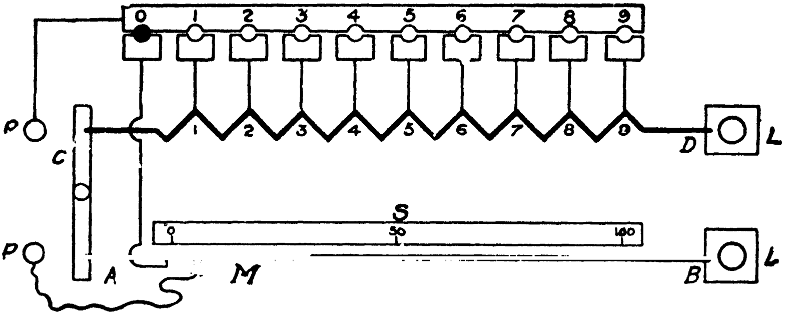


FIG. 1,523 —Diagram of apparatus for measuring low resistances based on the principle of the Kelvin double bridge In the diagram AB, represents a heavy piece of resistance metal of uniform cross section and uniform resistance per unit of length, CD, is another piece of resistance metal of smaller cross section, and the two are joined together by a heavy copper bar, AC, into which both are silver soldered, LL, are the current terminals and PP, are the pressure terminals The resistance of AB, between the marks 0 and 100, on the scale S, is .001 ohm From the point 1 on the resistance CD, to 0, on AB, is also .001 ohm, from 2 to 0 is .002 and so on, and from 9 to 100 is .01 ohm The slider M, moves along the resistance AB, and its position is read on the scale S, which is divided into 100 equal parts and can be read by a vernier to thousandths. Subdivided in this way the resistance between the top off points PP, may have any value from .001 to .01 ohms by steps of .000001 ohm

Then $$a = \frac{r - AR}{A+1} \qquad (6)$$

In most cases a check test can be applied by connecting the faulty wire to X1, and the good wire to X2, and then varying the rheostat until a balance is obtained. It may be necessary to place the ratio dial switch on a different setting than that used for formula (6). Let R′ = new value of R

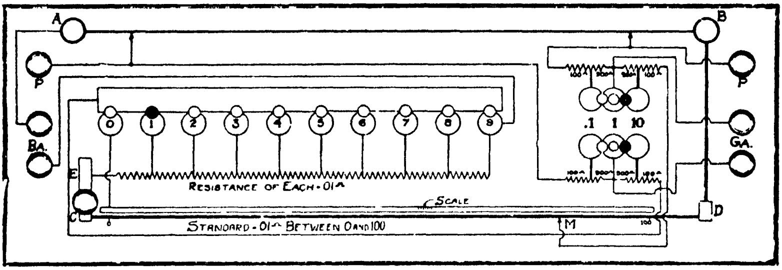


FIG. 1,524.—Kelvin bridge. This includes a low resistance standard of .1 ohm variable by steps of .00001 ohm, a set of ratio coils, and a holder for rods or wires to be measured, with a scale to measure their length. It is also provided with heavy flexibles to be used in measuring the resistances of irregularly shaped pieces. The connections are clearly shown in the diagram. The range of measurements of this bridge is: 1 ohm to .1 ohm by steps of .001 ohm readily estimated to .0001, .1 to .01 ohm by steps of .0001 ohm readily estimated to .00001; .01 ohm to .001 ohm by steps of .00001 ohm, readily estimated to .000001; .001 ohm down by steps of .00001 ohm, readily estimated to .000001 ohm.

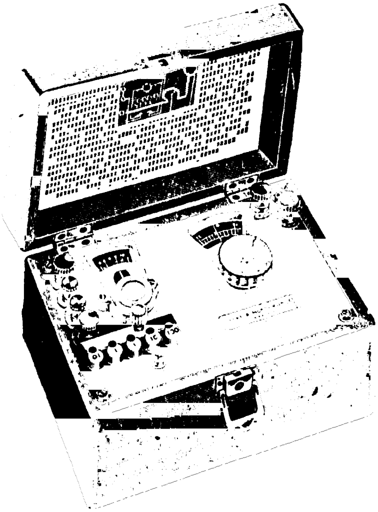


FIG. 1,525.—Kelvin bridge ohm meter for measuring low resistance. It is similar in construction to the familiar Wheatstone bridge type ohm meter. ***Accuracy:*** 2% between .0001 ohm and 11 ohms; ***Galvanometer:*** sensitivity 1. megohm, resistance 40 ohms; ***General:*** five ranges. Self contained No. 6 dry cell battery.

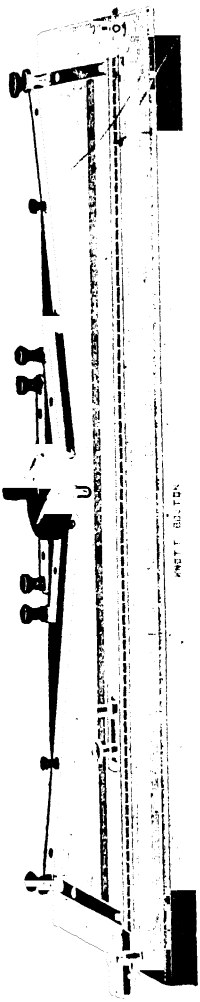


FIG. 1,526.—Knott University Reversible slide wire meter bridge for measuring resistances with low *e.m.f.* where the plug form of resistance box would be useless. With both mercury cup and binding post contact, Latimer-Clark commutator, tension spring for bridge wire, contact slide with rack and pinion, and fine adjustment with push button locking device for holding the contact at any desired point. Four gaps are provided for ratio coils and extension coils which are also available for inserting coils in the conventional Wheatstone bridge arrangement. The commutator may be removed, leaving available two extra gaps which may be required in special work.

Then $$a' = \frac{A(r+R')}{A+1} \quad\ldots\ldots\ldots\ldots\ldots(7)$$

The distance to the fault can be obtained from the formula:

$$d = \frac{a}{b}L \ldots\ldots\ldots(8) \text{ or } d' = \frac{a'}{b}L \ldots\ldots\ldots(9)$$

in which a and a′ = the resistances to the fault by formulæ (6) and (7) respectively, b = the resistance to the faulty wire = ½ the resistance of the loop where good and bad wires are of the same size and are in the same cable and L = the length of the cable.

Example.—The total resistance of a loop, one wire of which was faulty was found to be 290 ohms. The ratio dial switch was placed at .1, and a balance obtained with a rheostat setting of 1,910. The resistance to the fault from post X2, using formula (6), is

$$a = \frac{290 - .1 \times 1{,}910}{.1 + 1} = 90 \text{ ohms.}$$

For a check test a balance was obtained with a rheostat setting of 700.

Using formula (7) the resistance to the fault from post X1, is

$$a = \frac{.1\,(290 + 700)}{.1 + 1} = 90 \text{ ohms}$$

NOTE.—***Poor Connections.*** It is of primary importance that good electrical connections be made throughout the circuit. If one is to rely upon an inexperienced assistant for making joints and connections on poles and elsewhere, much annoyance may be experienced. Resistance caused by poor connections in the loop circuit will enter directly as an error in the location, if, for instance, the assistant does not make a good connection in joining the faulty to the good wire but introduces a resistance of ¼ ohm, where the wire is No. 22 B. & S. copper, the location will be about 16 feet in error. Experience will teach one, however, to detect in most cases improper and poor connections by the use of the check methods, or by duplicating some of the tests.

Location of Opens.—Disconnect the galvanometer and battery by turning the respective switches to the position marked OUT. Connect a telephone receiver to the Ga, posts and a source of alternating current such as produced by a "tone test" or buzzer to the Ba, posts. The buzzer should be placed as far as possible from the testing set so that its noise will not be heard by the operator.

Set the ratio switch on M1,000, which places 1,000 ohms in the bridge arm circuit and place the switch at the back of the set in the position marked MURRAY. The telephone can be permanently closed by means of the lock-down key in its circuit, by turning the arrow stamped upon its top away from the operator when in front of the testing set. The key in the buzzer circuit cannot be permanently closed. If a receiver with a head band be used, the operator's hands will be free to close the buzzer key and manipulate the rheostat.

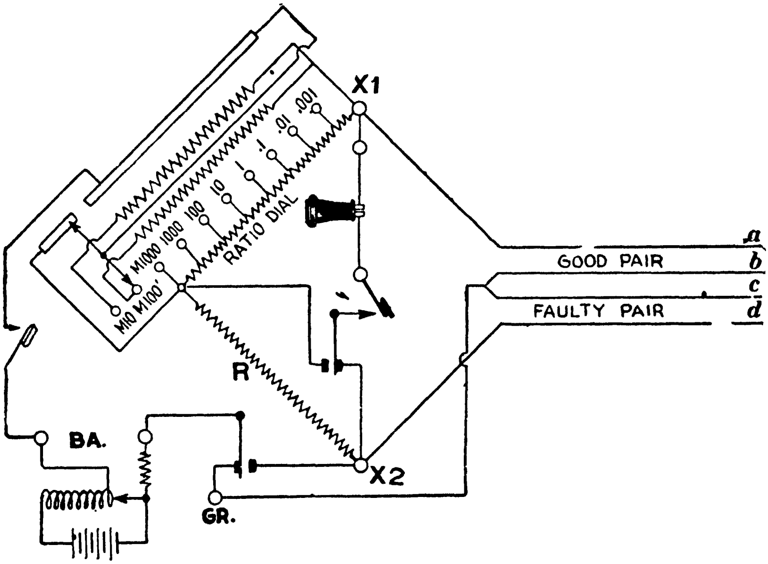


FIG. 1,527.—Connections for testing for locations of opens.

Connect the open wire to post X2, and a good wire of any other pair in the same cable to X1. Connect the mates of the wires used for posts X2.

and X1, to the post Gr, but do not ground. The connections will then be as indicated in fig. 1,527, in which d is the broken conductor and c, its mate. a and b, are the wires of any other pair in the cable. All wires must be free from grounds and crosses.

Vary the rheostat until a balance is obtained.

Letting R = rheostat reading
L = length of cable in feet
d = distance to the open in feet
A = ratio dial setting

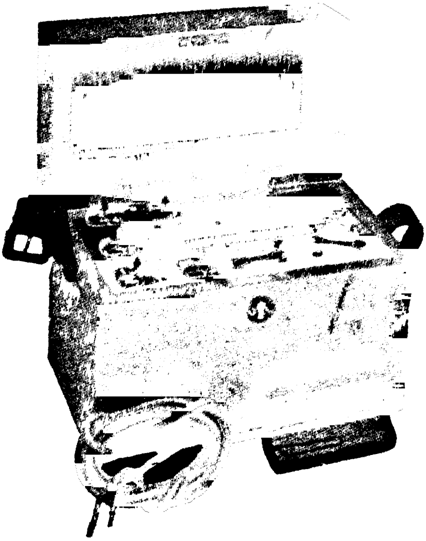


FIG. 1,528.—Queen wireless test set or inductive fault finder. This cable test set is used for locating crosses, grounds, split pairs, etc., by means of an exploring coil. This set may be regarded as a *vernier* to the location made with a Wheatstone bridge. Its results depend upon sound and does not involve any mathematical formula It is also arranged to give a trouble tone

Then $$d = \frac{AL}{R} \qquad (10)$$

If a balance cannot be obtained with ratio dial set at M1,000 then set for M100 or M10 and substitute said values of 100 or 10 for A, in the formula. If a balance cannot be obtained after using all settings down to and including M10, it indicates that the open is less than .001 of the length of the cable from X2. In such cases set the ratio dial on .001 and use the formula

$$D = \frac{L}{R + 1{,}000}$$

In this way location can be made to $\frac{1}{11{,}000}$ of the length of the cable.

Balance in the Telephone.—The bridge is balanced when the point is found where the noise in the telephone is least. The procedure is to place all the dials in the rheostat at nine and successively rotate the thousands, hundreds, tens and units dials finding a position where the sound in the telephone is a minimum.

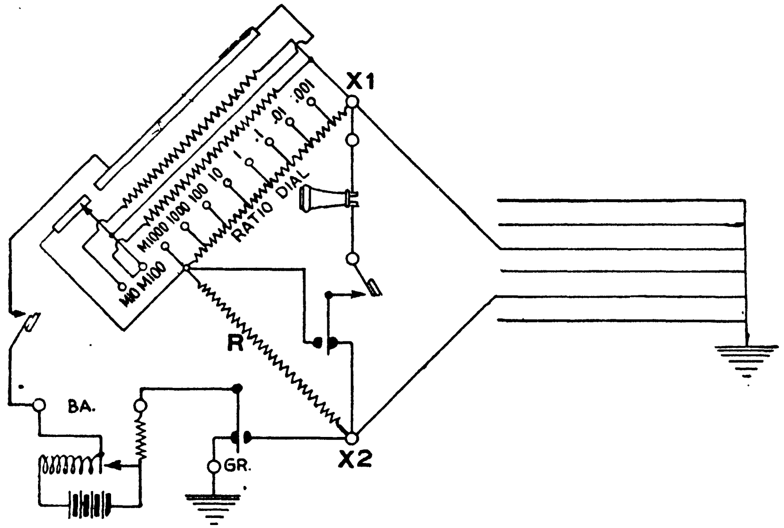


FIG. 1,529.—Connections for tests of telegraph and other multiple cables.

Example.—An open wire in a cable 5,280 feet long was connected as shown in fig. 1,527. A balance was obtained with the ratio switch at M1,000 and a dial setting in the rheostat of 1,320 ohms. The distance to the open from post X1, using formula (10), is

$$d = \frac{1{,}000 \times 5.280}{1.320} = 4{,}000 \text{ ft}$$

Tests of Telegraph and Other Multiple Cables.—In cables of this class, in which the wires are not grouped in pairs, instead of balancing the capacity of the open wire to its mate against that of a good wire and its mate, as in the foregoing test, the relative capacities to ground of an open wire and a good wire are balanced.

The connections differ only in the use of two wires instead of two pairs and in grounding.

The switch is placed, as described for location of opens in telephone cables. Connect the open wire to the post X2, and a good wire in the same cable to the post X1. If possible all the other wires should be grounded to the sheath of the cable as well as the section beyond the break. Connect the post Gr, to ground, as in fig. 1,529.

Let R = rheostat reading
L = length of cable in feet
d = distance to the open in feet
A = ratio dial reading

Then

$$D=\frac{AL}{R} \quad \dots\dots\dots\dots\dots\dots\dots\dots (11)$$

If a balance cannot be obtained after using all settings down to and including M10, then use the .001 ratio setting and the formula

$$d=\frac{L}{R+1{,}000}$$

as in the case of the telephone cable.

Method of Picking Out a Grounded Wire.—Set the ratio dial on M1,000, and the switch at the back of the set for the Varley loop.

Connect Gr, posts to ground or cable sheath and connect the wires in the cable one after the other, to post X1. The faulty wire will be detected by a strong deflection of the galvanometer needle when the battery and galvanometer keys are closed. The galvanometer is sufficiently sensitive to give a readable deflection for 1 volt through 1 megohm and hence a very high resistance ground or fault can be detected.

To Use as a Resistance Box.—Connect to binding posts X2 and R. When using the rheostat separately the position of the switch is immaterial.

To Use Galvanometer in Series with Battery.—Connect to binding posts Gr and X1, set the ratio dial on M1,000, the switch for Varley loop.

The galvanometer is deflected by closing the battery and galvanometer keys.

To Use Outside Battery.—Connect battery in at Ba, posts, having disconnected the contained battery by setting the BA, switch on OUT.

To Use Outside Galvanometer.—Connect outside galvanometer to the Ga, posts, having disconnected the contained galvanometer by setting the Ga, switch on OUT.

Notes on the Varley Test.—This test is extremely useful, particularly on multiplied telephone cables. By multiplied, one is to understand that the same pair of wires is tapped into a number of different terminals, as shown in fig. 1,530. This pair is multiplied at four points, A, B, C and D. When the arms of the Wheatstone bridge are made even in the Varley test, the formula $R = r - 2a$ means that the resistance in the rheostat when balance is obtained is equivalent to that of both sides of the pair from the end where the helper makes his connection, to the fault. It is an easy matter for the tester to memorize the constants for the number of feet per ohm of the three or four most common sizes of wire used for telephone cables.

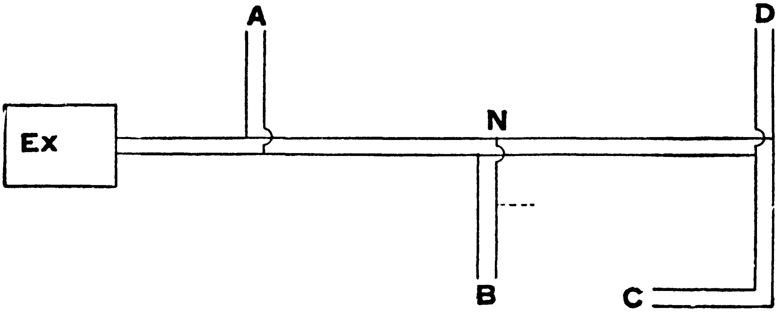


FIG. 1,530.—Diagram illustrating the term *multiplied* to accompany notes on the Varley test.

Knowing the gauge of the wire it is merely necessary to multiply one-half the number of feet per ohm of that size wire by the rheostat reading in order to get the distance to the fault in feet.

The application of this to multiplied cable may be readily shown. Assume a fault at X. The tester is at Ex, and the helper connects the two wires together, say at C. The Varley test then gives the onms back from C, to the apparent location of the fault (in this case at N, where the pair to B, is tapped on the main cable). Having the resistance from C to N, a rough calculation involving feet per ohm multiplied by Varley reading gives the distance from C, to the apparent fault.

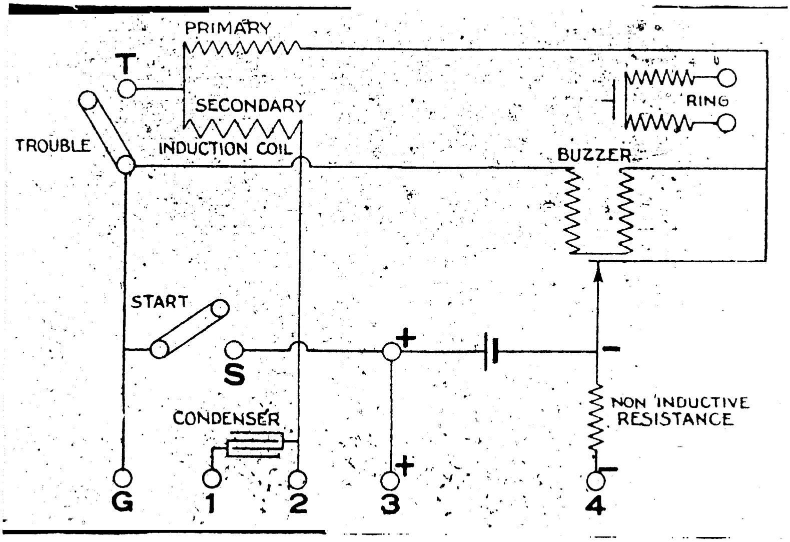
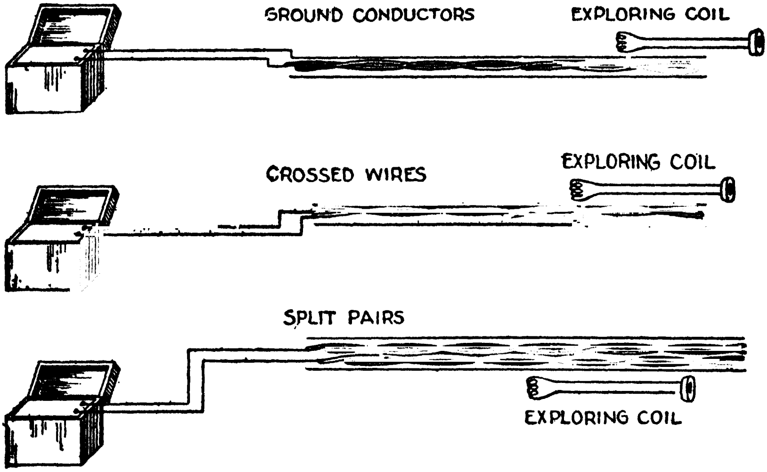


FIG. 1,531.—Queen wireless test set or inductive fault finder; diagram of instrument.

From the cable diagram this distance can be read which should be about that between C and N. The connection at C, is then removed and replaced on the same pair at B, and the above process repeated.

In order not to be misled by the variation in resistance due to changes in temperature, it is well for the tester to measure some known length once each week or two and divide distances by resistance to obtain the proper constant. That this is quite important may be understood from the fact that for underground cable the constants will vary 10% between summer and winter temperatures.

In cases where there are cables of two different gauges spliced together it is easy to figure out the location without making any gauge correction. For instance, consider the case where a pair of wires of one gauge is attached to another pair of equal length but different gauge, the total loop resistance being, say, 40 ohms and the Varley test showing a balance at 10 ohms with equal bridge arms. This would mean that the fault was 5 ohms from the far end. Knowing the two gauges one can estimate mentally if this amount of resistance will carry the location beyond the junction point of the two sizes. If not, then multiply by the constant for the gauge wire on the far end, which will give directly the distance from that end to the fault.



FIGS. 1,532 to 1,534.—Queen wireless test set or inductive fault finder; diagrams of connections for use.

In any case where the balancing resistance carries the location into the section nearest the locator, then instead of multiplying the constant by the rheostat reading, subtract this reading from the total loop resistance and multiply the difference by ½ the constant for the gauge wire nearer to the tester. This method is lengthy of explanation but when once one gets the idea, these processes are mainly mental and really take very little time.

Tests may be made this way on all but the very shortest cables and not then, for the reason that ordinary bridge sets are not sub-divided below one ohm in the rheostat. Very often, however, one is able to interpolate proportionally to the deflection of the galvanometer when a close approximation is necessary. However, when it comes to a question of inches on a short length of wire, either the Murray test or the Varley test with unequal bridge arms should be used for accuracy.

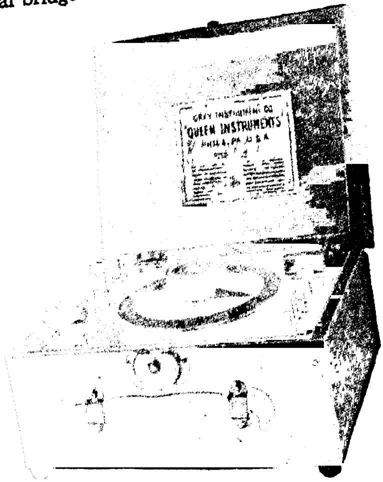


FIG. 1,535.—Queen ground resistance and direct reading ohm meter for measuring the resistance of ground connections and driven grounds. This tester although direct reading is arranged on the Wheatstone bridge principle, thereby giving a uniform scale with maximum accuracy throughout its entire range. It is balanced by a telephone receiver. The use of the bridge rheostat in the form of a slide permits measurements to be made with facility and speed. ***The method of use*** is the "three ground test" which requires the determination of the combined resistance of the ground under investigation and of two auxiliary grounds which are connected in series with it and with each other. To increase the range of this tester, a 10 multiplier in the bridge arms is provided, permitting its use as a general purpose ohm meter for ordinary resistance measurements, up to a maximum of 2,700 ohms. The direct scale reads from 0 to 270 ohms on one ohm divisions. The single scale division can be easily estimated to one half ohm. When the multiplier is in circuit the scale range is 0 to 2,700 ohms. Binding posts and switches are arranged so that an external galvanometer can be connected to the instrument, as some may prefer a galvanometer for balancing in place of the telephone when measuring ordinary resistances. When used for ground resistances a telephone is necessary.

The formula $R = r - 2a$ is the universal Varley formula for equal bridge arms. Knowing the gauge of the bad wire it is possible to obtain the location by solving for a.

When a good wire of large size is used and the fault is near the far end of the smaller wire it sometimes happens that a balance cannot be obtained with the bad wire in series with the rheostat. In these cases it is necessary to reverse the wires on their respective binding posts. Then balance as usual and use the formula with R, negative or $-R = r - 2a$.

$$a = \frac{R + r}{2}$$

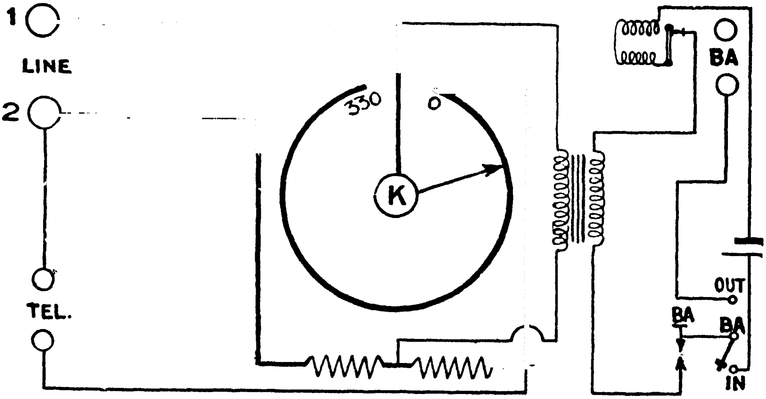


Fig. 1,5 6.—Queen ground resistance tester; diagram of connections. ***Directions for operating.*** Connect permanent ground and one of the test grounds to line posts 1 and 2. Connect receiver to posts "TEL." Close PA, key by depressing and turning ¼ turn to close permanently or without turning it can be tapped. Adjust rheostat slide K, unit until no sound is heard in the receiver. The scale reading is the resistance between the two grounds. Make the same test using the other test ground and permanent ground, and then again using the two test grounds. Add the three readings and divide by 2 and subtract the reading taken between the two test grounds and this will be the resistance of the permanent ground. To use external battery place switch at "out" and connect battery to posts "BA."

The above described loop methods, the Murrav and Varley, are the ones most frequently used. Some other loop methods and various modifications of these tests have been worked out to meet specific requirements.

The Potentiometer.—For the rapid and accurate measurement of voltage. current, and resistance, the potentiometer can

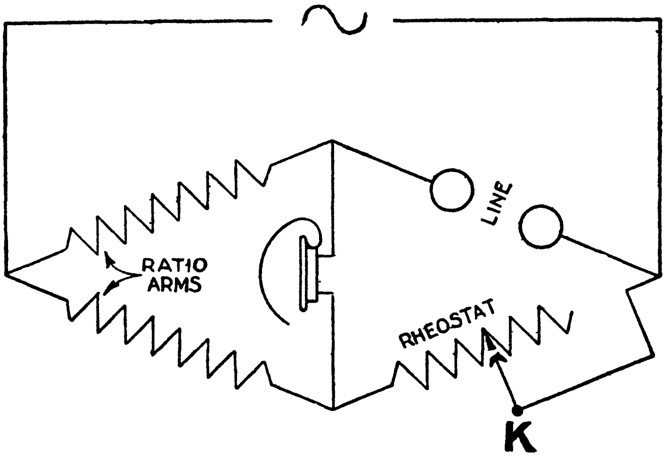
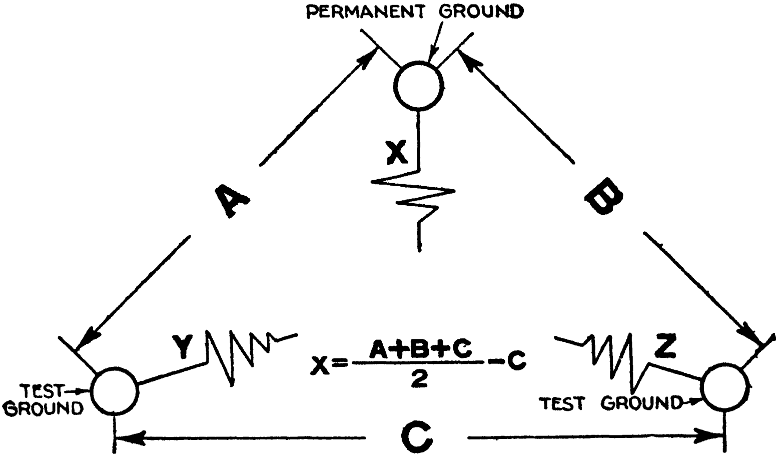


FIG. 1,537.—Queen ground resistance tester; simplified diagram.



$$X=\frac{A+B+C}{2}-C$$

FIG. 1,538.—Queen ground resistance tester: theoretical diagram.

be recommended. Those in charge of electric light and power companies, and also those who purchase large amounts of electrical energy are realizing, more and more, the necessity of having satisfactory primary standards with which to check their volt, ampere-, and watt-meters.

When it is realized that an error of one per cent. in a commercial instrument means an error of one dollar one way or the other in every one hundred dollars charged, the need of such standardization apparatus becomes at once apparent.

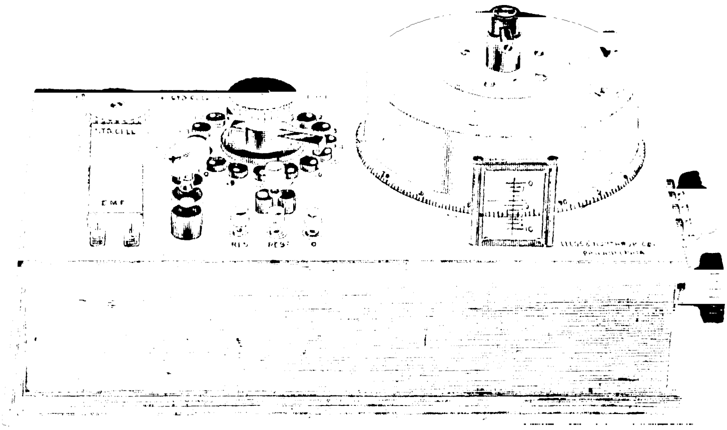


FIG. 1,539.—Leeds and Northrup Type K Potentiometer. It has no internal resistance which gives high sensitivity. There are no contact resistances in the potentiometer circuit proper. The last one tenth volt is covered by a slide wire which facilitates following a fluctuating voltage. The current flowing through the potentiometer may be checked without disturbing the dial or slide wire setting. When used with any cadmium cell the potentiometer is direct reading, requiring neither calculations nor corrections. The construction of the instrument is further shown in the diagram fig. 1,540.

The potentiometer, it should be noted, relies for its accuracy only upon the constancy and accuracy of resistances and upon standard cells.

The instrument consists of an arrangement of carefully standardized resistances for measuring voltages in comparison with a standard cell. It is used for accurate measurement of voltages, currents and resistances.

In place of a series of standardized resistances, a slide wire may be used as in fig. 1,540.

With the materials now available, and the skill which has been acquired in their manufacture, both the resistances and the standard cells are

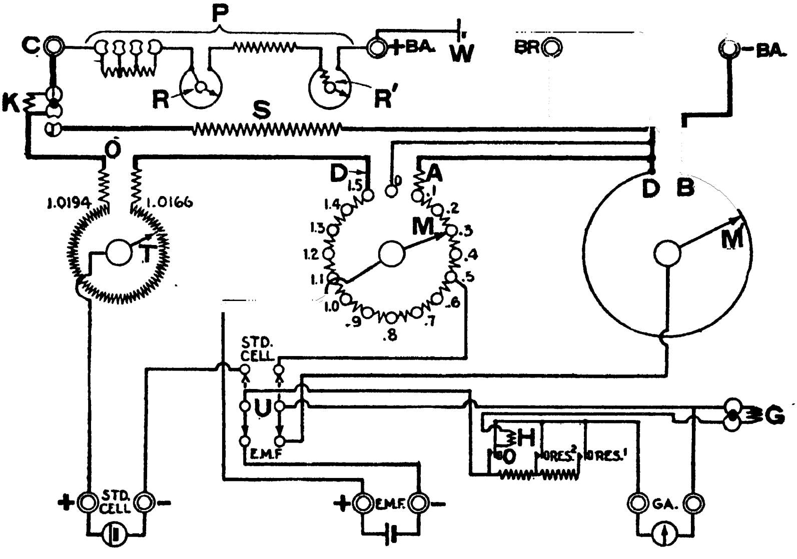


Fig. 1,540.—Diagram showing connections of Leeds and Northrup type K, potentiometer. ***The essential*** part of the instrument consists of 15 five ohm coils AD, adjusted to equality with a high degree of accuracy, connected in series and having in series with them a slide wire DB, the resistance of which from 0 to 1,000 on its scale (the entire scale extending from 0 to 1,100) is also five ohms. A contact point M, makes contact between any two of the five ohm coils, and a contact point M', makes contact at any point on the slide wire DB. Current from the battery W, flows through these resistances, and by means of the regulating rheostat P, it is adjusted to exactly one fiftieth of an ampere. Consequently the fall of potential across any one of the coils AD, is .1 volt and that across the slide wire DB, is .11 volt. By placing the contact point M', at zero, and moving the contact M, the fall of potential between M and M', may be varied by steps of .1 volt, from 0 to 1.5 volts. By moving the contact point M', along the wire, the fall of potential between M and M', may be varied in infinitesimal steps.

obtainable which are remarkably constant, and both can be readily checked for accuracy.

The potentiometer is essentially an instrument for comparing differences of potential and the various designs differ in the method of dividing the potential drop into decimal steps. Such instruments have either high or low resistance circuits, and while each possesses inherent advantages it also presents disadvantages.

The high resistance potentiometer requires a very small amount of current so that a long series of measurements can be made without the necessity of readjusting the current in the potentiometer circuit. It, however, involves a larger number of switches for manipulation to establish a balance and is therefore not so convenient to manipulate in addition to its higher cost.

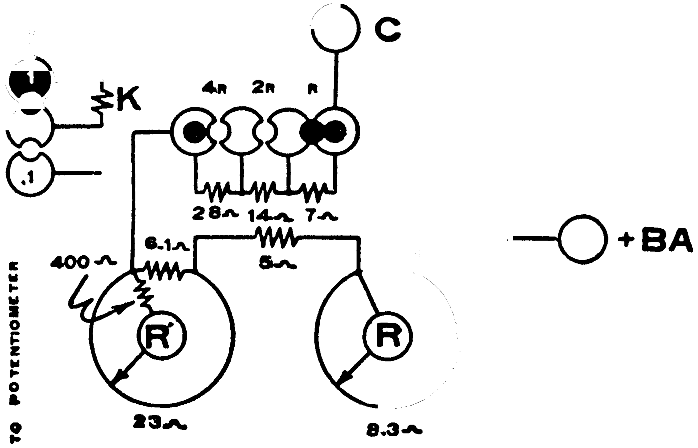


FIG. 1,541.—Regulating rheostat of Leeds and Northrup type K, potentiometer. This is P, of fig. 1,510. The actual connections are shown in fig. 1,541. This rheostat is mounted in the right hand end of the potentiometer. Rough adjustment is made by R, and fine adjustment by manipulating R'. The 23 ohm resistance of the latter dial is shunted by a resistance of 6.1 ohms, making possible very fine regulation. On the fine adjustment dial there is, in series with the contact, a fixed resistance of 400 ohms, which makes negligible the effect of possible variable contact resistance.

In low resistance potentiometers the current required is larger and variation in resistance, especially of the battery, will vary the current to an appreciable extent, thereby necessitating more frequent adjustment of the regulating rheostat and consequent repeated checking against the standard cell to insure the correctness of the E.M.F. under test The low resistance type eliminates the use of contacts directly in the potentiometer circuit, thereby confining it to the use of only one series of resistances and a slide wire. It has the advantage of greater convenience of manipulation as compared with the high resistance potentiometer. In the design of low resistance potentiometers a slide wire is used for the final setting. Heretofore,

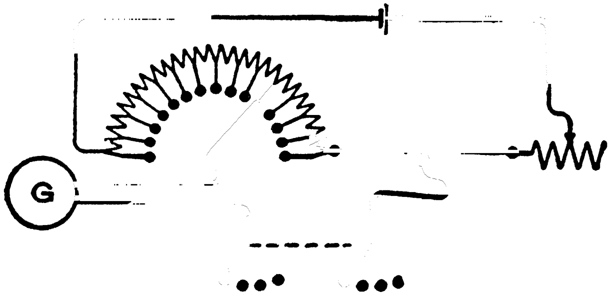


FIG 1,542.—Diagram of the Crompton potentiometer. ***In this instrument*** the resistance consists of fourteen coils, each of 10 ohms, in series with a straight wire, also 10 ohms resistance, thus forming a system of fifteen equal steps. Across the whole a pressure of 1 5 volt is applied from a secondary cell, thus providing 10 volt per step. Any fraction is then tapped off by means of a radial switch on the resistance coils and a sliding contact on the wire. The standardization is performed by adjusting a resistance in series with the whole until the standard cell employed indicates, by means of the galvanometer G, a balance at the point which represents its electromotive force on the basis given above.

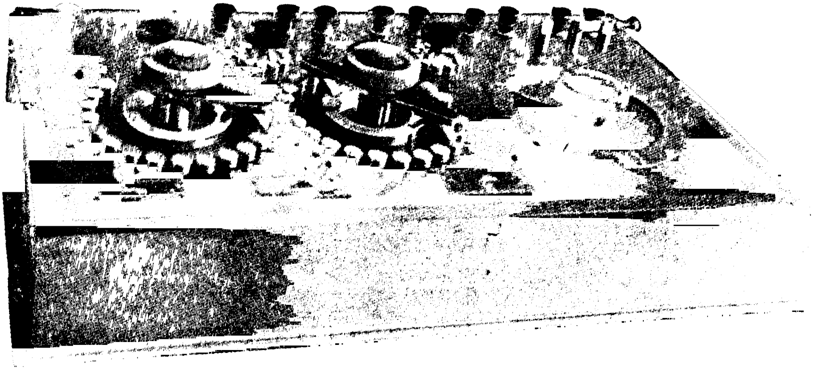


FIG. 1 543 —Queen-Gray standard potentiometer intermediate resistance type circuit. ***This instrument*** has a total resistance sufficiently high to permit the use of a switch in the main circuit without error and low enough to enable a slide wire of only one turn to be used for the last setting.

it has been the practice to use a slide wire of ten or eleven turns in order to make use of a wire of suitable size for mechanical strength and also to have the requisite length to accurately sub-divide the potential in the wire to a fraction of a milli-volt. The use of such a long wire necessitates the moving of its contact through ten or eleven turns.

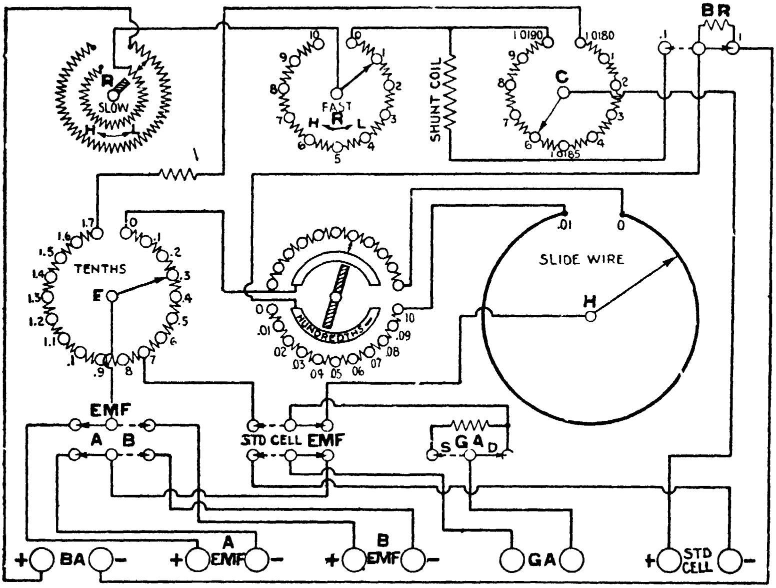


FIG. 1,544.—Complete diagram of connectors of Queen-Gray standard potentiometer. The main potentiometer circuit consists of 17 fifty ohm. coils in the "tenths" switch, 10 five ohm coils in the "hundredths" switch (intermediate switch) and the 5 ohm "slide wire." The current to operate this potentiometer is .002 ampere, therefore the fall of potential over each 50 ohm coil will be .1 volt, for each 5 ohm coil .01 volt and for the entire slide .01 volt. The slide wire is divided into 200 parts and consequently a single division is equivalent to .00005 volt. The single division can be easily estimated to .2 thereby reading to .00001 volt which can be further reduced .1 or .000001 volt by means of a shunt coil. It is thus noted that means are provided for an adjustable potential from .000001 volt to 1.7 volts which can be extended to 17 volts when .02 ampere is made to flow through the potentiometer.

The intermediate resistance potentiometer is a type having resistance intermediately between the high and low resistance types.

The Potentiometer Principle.—Familiarity with the principles underlying any measuring instrument is valuable to the user or prospective user of the device; for not only does it enable him to secure his results more quickly and accurately, but it also gives him confidence in the results of his work.

A potentiometer is a device *for measuring potential differences by either totally or partly balancing the unknown against a variable potential difference, the value of which is known by reference to a standard of electromotive force.*

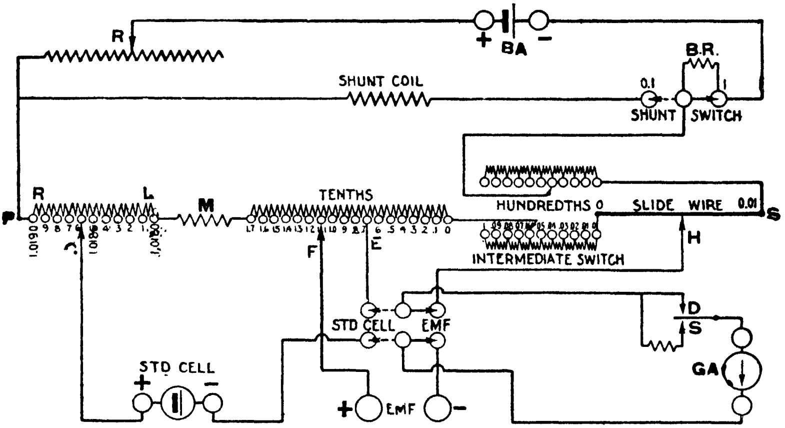
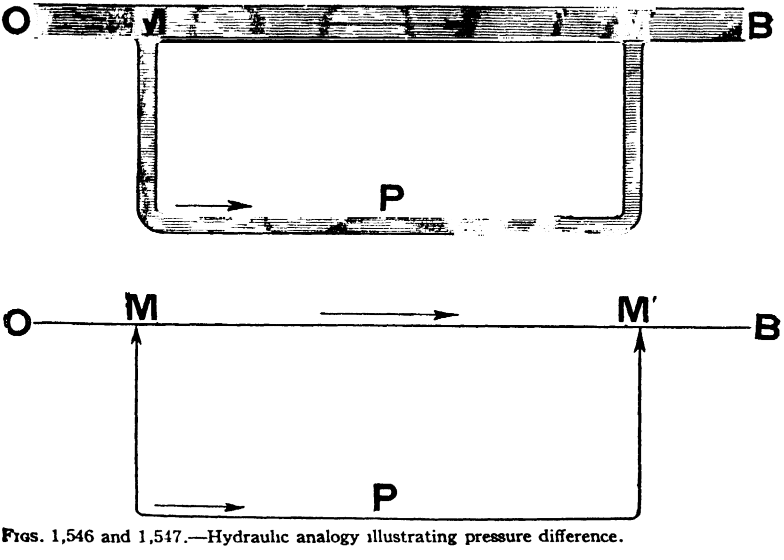


FIG. 1,545.—Simplified diagram of connections of Queen-Gray standard potentiometer. The instrument is arranged so that its settings may be reduced .1, thereby reading to .0000001 volt. This is accomplished by shunting the main potentiometer circuit with the "shunt coil" shown in the diagram, so that the combined resistances will be exactly .1 of the unshunted potentiometer circuit. Therefore the fall of potential across all the resistances will be .1 of their nominal values. The switch when placed at .1 (see upper right of fig. 1,544) not only places the "shunt coil" in circuit, but also adds to the circuit a resistance of such value that the total resistance of the entire potentiometer circuit is the same, otherwise .002 ampere would not flow and the fall of potential across each part of the potentiometer would not be exactly .1 of its nominal value. Placing the switch at position 1, disconnects the "shunt coil" and short circuits the ballast resistance B.R. thus setting the potentiometer for normal use.

If the two potential differences be exactly balanced, we have the usual "null" potentiometer; if partly balanced, the indicating instrument (galvanometer) gives a measure of their difference, and we have a deflection potentiometer.

As an aid in comprehending the principles involved in any potentiometer, an analogy is useful.

In fig. 1,546, let OB, represent a section of a pipe carrying a current of water. Between the points M and M′, a pressure difference exists, which, other things remaining unchanged, will increase with the distance between the points in question, the higher pressure being at M. If the pipe be tapped at M and M′, and a branch pipe MPM′ attached, a current flows, as indicated, and the current results from the pressure difference.



Figs. 1,546 and 1,547.—Hydraulic analogy illustrating pressure difference.

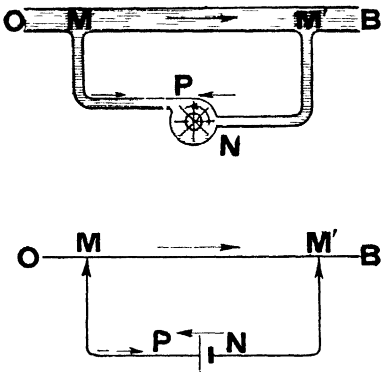
Pressure difference in hydraulics is analogous to potential difference in electricity. A current flows in a conductor only when a potential difference exists.

If, in the preceding paragraph but one, the terms "conductor," "electricity," and "potential difference" be substituted, respectively for "pipe," "water" and "pressure difference" and reference is made to fig.

1,547 instead of 1,546, the same statements hold true without modification. The paragraph referred to will then read: Let OB, represent a section of a conductor carrying a current of electricity.

Between the points M and M′, a potential difference exists, which, other things remaining unchanged, will increase with the distance between the points in question, the higher potential being at M. If the conductor be tapped (contact made) at M and M′, and a branch conductor MPM′, attached, a current flows, as indicated, and the current results from the potential difference.

Referring next to fig. 1,548, a rotary pump may be inserted in branch MPM′, rotating in the direction indicated by the arrow.



Figs 1,548 and 1,549.—Hydraulic analogy illustrating maintenance of pressure difference between N and P.

By the action of the pump, a pressure difference can be maintained between N and P, with the higher pressure at N. It is easy to conceive of the pump being driven at constant speed, so as to maintain a steady pressure difference; and to imagine such strength of current in OB, that the pump exactly balances the pressure difference between M and M′. In this case, no current could flow through the branch MPM′, because the tendency to flow in one direction would be exactly neutralized by the tendency to flow in the opposite direction; and this absence of current could be shown by some kind of flow indicating instrument inserted in the branch.

With the same substitution of terms as before, the identical reasoning applies to fig. 1,549.

Here a battery is represented as the source of potential difference analogous to the pump as the source of pressure difference. With these preliminary ideas, we proceed to a consideration of electrical circuits only.

In the diagram fig. 1,550, the cell W, which may be an ordinary dry cell, causes a current to flow, in the direction indicated by the arrow, through the resistance OB.

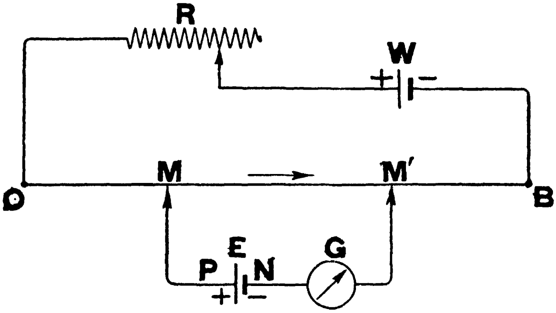


Fig. 1,550.—Elementary potentiometer circuit illustrating condition of balance.

The result is a potential difference between any two points on OB, say between M and M′, due to the fall of potential through the resistance between the two points considered. With the current flowing as indicated, M, is at a higher potential than M′, that is, M, is positive with respect to M′.

Now consider the circuit MEGM′, in which E, represents any source of steady potential difference and G, a galvanometer.

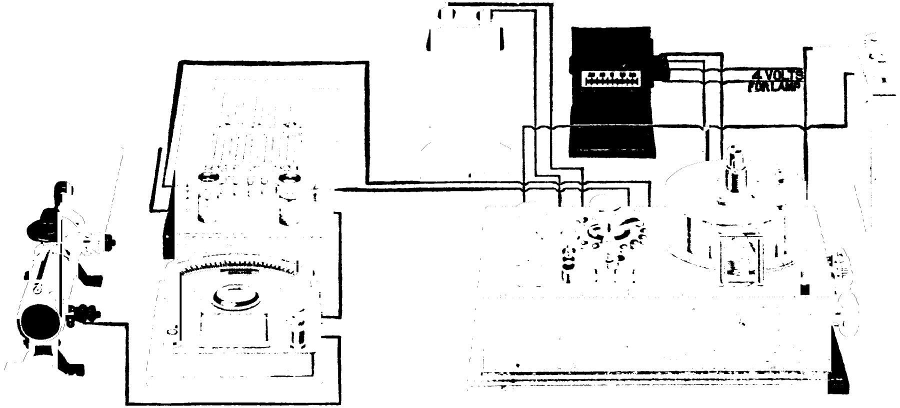


FIG. 1,551.—Leeds and Northrup assembled equipment. Resistance standard which makes this equipment a suitable one for current measurements up to 15 amperes. For voltage measurements, a volt box would be used in place of the standard resistance.

The point P, is brought to the same potential as M, by connecting them with a conducting wire MP, both being positive; then if the potential of N, be as much below P, as that of M′, is below M, obviously N and M′ must be at the same potential. The net result is that no current can flow in this circuit. This is indicated by the fact that the galvanometer, which is merely a current indicating instrument, shows no deflection. If, with the value of E, remaining constant, the position of M or M′, were shifted, a current would immediately flow, because the fall of potential along MM′, would then be either greater or less than the fixed value of E. The galvanometer would no longer show a balance, but would be deflected either to the right or left of its zero position. Therefore, experimentally, two points M and M′, can be found between the ends of the resistance OB, at which the galvanometer shows a balance.

It is immaterial where, on OB, the two points are located, as long as the resistance between them has a proper value, and M, remains at the higher potential. With E, greater or smaller, the distance, and consequently the resistance, between the points would correspondingly have to be increased or decreased, respectively, in order to maintain this condition.

It is thus seen that it is possible to oppose two potential differences in such a way that one will be exactly balanced by the other; and that a galvanometer, as an indicator, shows when such a condition exists.

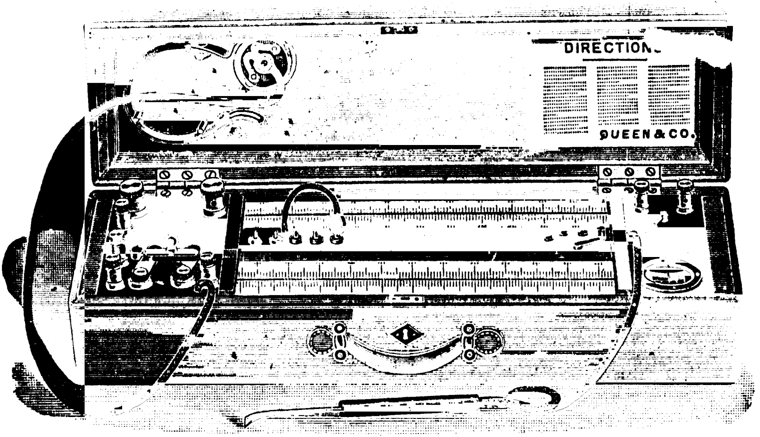


FIG. 1,552.—Queen slide wire bridge. It consists of a portable slide wire, Wheatstone bridge arranged to read directly in ohms in addition to its use for locating crosses and grounds. It is complete with battery, galvanometer and telephone receiver. The bridge is balanced by moving the hand stylus until the galvanometer shows no deflection or until there is no sound in the telephone receiver. In order to provide a wide range of measurement and maximum accuracy, ratio coils or multipliers having values of 1, 10, 100, 1,000 and 10,000 are provided. The scale of the instrument is arranged in two parts, one of which indicates ohms and the other is divided into uniform divisions for use when locating crosses and grounds by the Murray and Varley loop methods. A small induction coil is included so as to furnish an alternating current when using the telephone receiver.

Assuming the value of E, to be exactly 1 volt, M and M′, could then be set with, say 1,000 arbitrary resistance units between them. By means of the regulating rheostat R, the current in OB, could be adjusted until the galvanometer showed zero deflection, indicating the potential difference between M and M′, to be equal to that of E.

Leaving the current in OB, unchanged, it is noted that the fall of potential along the resistance OB, is exactly 1 volt for each 1,000 units of resistance, or 1 millivolt per unit, because the current is the same in all parts of OB. This arrangement merely assumes that W, has a voltage high enough to produce the fall of potential as described. Its voltage must, of course, be higher than the potential difference of E.

Still leaving the current in OB, unchanged, substitute for E, another source of potential difference, this time of unknown value. In general, the relative positions of M and M′, will have to be shifted to restore the balance. Having found the balance point, the number of units of resistance between M and M′, will represent the number of millivolts in the potential difference being measured.

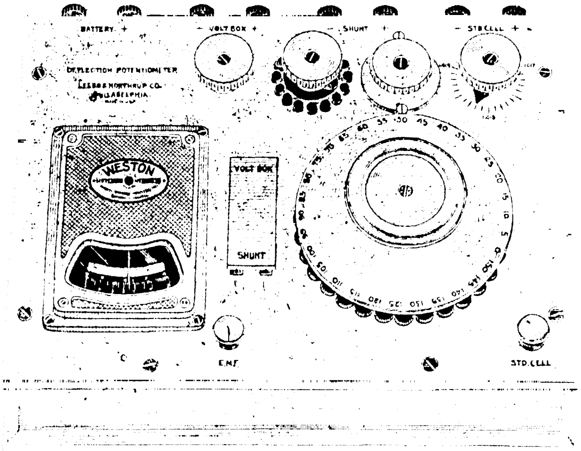


FIG. 1,553.—Brooks Model 7 deflection potentiometer. The deflection potentiometer finds its greatest use in laboratories where large numbers of *d.c.* deflection instruments have to be calibrated or checked. Before the deflection potentiometer was available, such measurements were made against "laboratory standard" deflection instruments and these in turn were checked against a null potentiometer. While the deflection potentiometer is not as accurate as the null potentiometer, it is more accurate than the "laboratory standard" deflection instruments and for calibration work is more rapid than either. In measurements where the use of the deflection potentiometer eliminates the use of the "laboratory standard" deflection instruments, the over-all accuracy of the measurements is improved.

The fact that when the galvanometer shows a balance, no current flows in the circuit of which it is a component, deserves emphasis; because of this no current is taken from the source of electromotive force which is being measured. The importance of this is that the source of electromotive force undergoes no change due to the measurement. Likewise when standardizing the potentiometer, no appreciable current is drawn from the standard cell. For this reason, a standard cell, if used carefully, will last indefinitely, since it will never be required to deliver any but very minute currents, and these only during infrequent moments.

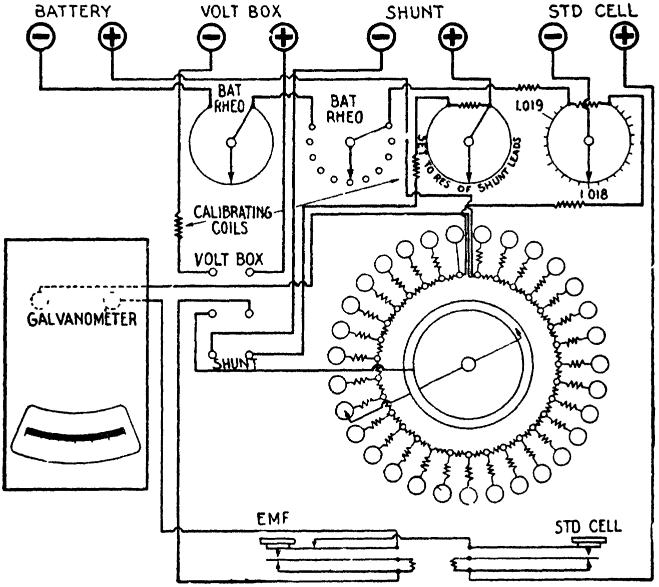


FIG. 1,554.—Diagram of internal connections of Brooks Model 7 deflection potentiometer, for a thorough understanding of the deflection potentiometer it is necessary to know the principles applying to potentiometers in general as explained in the accompanying text Briefly the deflection potentiometer is an instrument in which the electromotive force to be measured is balanced approximately against a known electromotive force. The small remaining difference is read from the deflection of a galvanometer The galvanometer serves the double purpose of detector in the potentiometer circuit and of a volt meter for measuring the unbalanced portion of the electromotive force. In order for the galvanometer deflection to accurately represent the unbalanced voltage, it is necessary that the total resistance in the galvanometer circuit remain unchanged for all potentiometer settings. The principal point in the design of a deflection potentiometer is the compensation which keeps the galvanometer circuit resistance at a constant value The compensation is made by means of auxiliary compensating coils, so connected in the main dial circuit, that the rotation of the dial does not alter the resistance in the galvanometer circuit. These compensating coils are shown in the above diagram. Fundamentally any potentiometer measures voltage, but the measurement of current requires only the addition of standardized resistances, or current shunts. The deflection potentiometer measures current by measuring the voltage at the potential terminals of a standard resistance, consequently the general theory is the same for the current, as for the voltage measurements.

The standard cell may be connected across one portion of AB, and the current adjusted, as described, and the unknown potential difference may be balanced against the fall of potential in another portion of AB. The connections for accomplishing this with a single galvanometer are shown in fig. 1,555.

Location of Opens.—These measurements are based on the fact that the capacity of wires in a cable is ordinarily a measurable quantity, which, in wire of uniform diameter, is proportionate to length. In making these tests, a fault finder is used together with a buzzer, dry cells to operate it, small induction coil, and telephone receiver. These instruments are to be found in any telephone exchange. It is best to locate the buzzer at some distance from the fault finder in order that it cannot be heard by the operator.

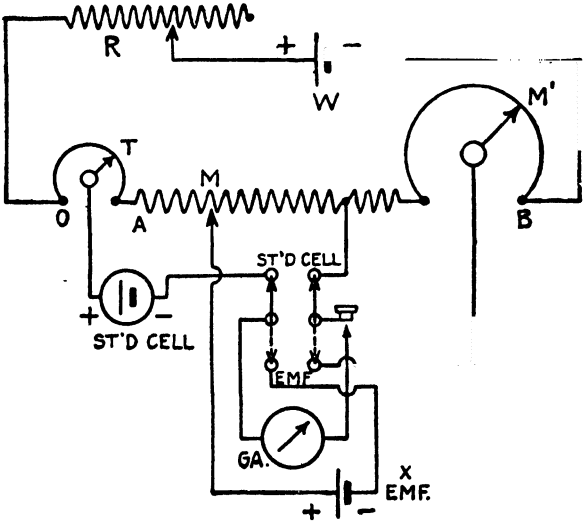


Fig. 1,555.—Potentiometer circuit diagram.

Before attempting locations for opens it is well to make the following measurements:

1. The insulation of the broken wire and the insulation of the good wire with which it is to be compared;

2. The resistance between the two sections of the broken wire should be measured.

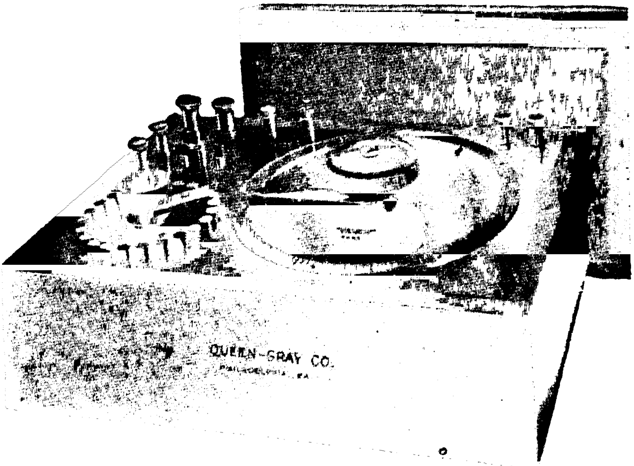


Fig. 1,556—Queen Gray simplified potentiometer The circuit consists of a group of 22 one hundred ohm coils (the dial switch at the lower left in illustration) and a slide wire, of exactly one hundred ohms, in series The current required for the circuit is 001 ampere, therefore the fall of potential over each coil is 1 volt and likewise 1 volt over the entire slide wire. The slide wire readable to 0001 volt (1 milli-volt) thereby giving the potentiometer a range from 001 volt to 23 volts The standard cell is connected to posts for the same and when the knife switch is placed at STD CELL its terminals are connected to the movable contacts of the dial switch and the slide wire To standardize the potentiometer in terms of the standard cell the potentiometer is set to the value of the standard cell and the regulating rheostat adjusted until the galvanometer is balanced The knife switch is then placed at E M F, and the galvanometer again balanced by adjusting the potentiometer for the unknown potential

This may be done by joining the broken wire and a good wire at the distant end of the cable and measuring the resistance of the loop. To ensure close locations, this resistance should be over 100,000 ohms. Fair locations can be made when the resistance is much lower and it is worth while to attempt it even if the resistance be as low as 10.000 ohms. The difficulty of determining the balance point increases as the resistance decreases.

Ques. Describe one form of potentiometer.

Ans. As shown in fig. 1,557, it consists of a fine German silver wire about 3 feet long stretched between the binding posts A, B, which are attached to a wooden base carrying a scale divided into 1,000 equal parts. There are three circuits, the terminal A, being included in each, one including the battery, and the other two the galvanometer. A three point switch connects the galvanometer in series with the standard cell SC, or the cell to be tested C, the circuits being completed by leads terminating in the sliding contacts M and S.

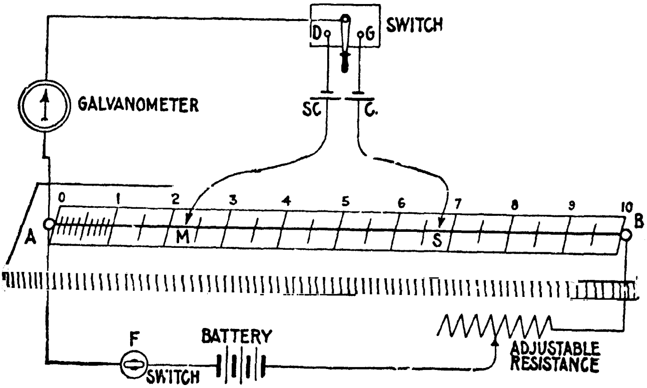


FIG. 1,557 —Diagram of potentiometer showing method of measuring the voltage of a cell. The potentiometer is simply a high resistance wire of uniform diameter stretched between two binding posts, A and B, in such a way that contact can be made at its ends and along its length Necessary circuits are plainly shown in the figure, SC, is a *standard cell* and C, the cell to be tested. M and S, are sliding contacts, connecting with the "slide wire"

Ques. Describe the method of measuring the voltage of a cell with a potentiometer.

Ans. Fig. 1,557 shows a method of comparing a pressure with that of a standard cell and is applicable whether the pressure of the cell to be tested be greater or less than that of the standard cell. In making the test the switch F, is first closed, then the other switch is moved to D and M, adjusted till galvanometer shows no deflection; similarly, the switch is moved to G and S, adjusted till galvanometer shows no deflection. Then, C : SC = AS : AM, from which C = SC×AS÷AM.

Example.—Let 1.016 volts be the known voltage of the standard cell SC, and the scale reading of AS, be 657, and of AM, 225 as in the figure. then

$$C=\frac{1.016\times657}{225}=2.966 \text{ volts}$$

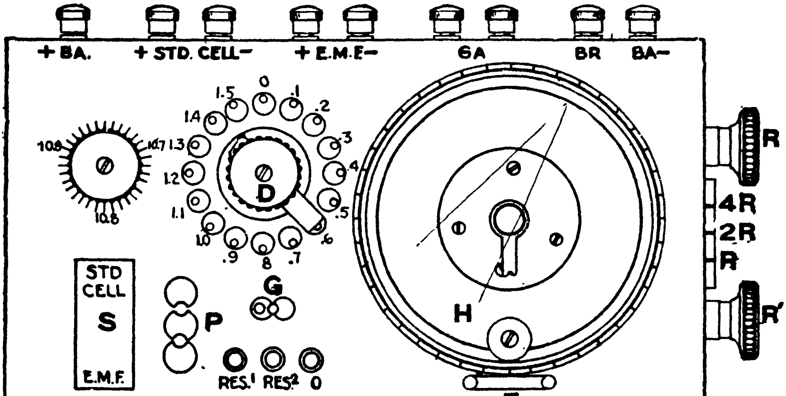


FIG. 1,558.—Leeds and Northrup type K potentiometer showing stampings on case indicating connections.

The arrangement may, however, be made direct reading, that is, the slide wire may have a scale of volts instead of lengths or resistances, as follows: Suppose the standard cell to have a pressure of 1.434 volts, the sliding contact M, is placed at the reading 1.434, and the adjustable resistance varied till the galvanometer shows no current. This means that the pressure between A and M, is 1.434, and consequently the pressures all along the slide can be read off the scale *in volts*. Hence, when S, has been adjusted to balance, the pressure of C, is read off the scale in volts.

How to Use a Potentiometer.—All connections must be made as indicated by the stamping on the instrument. Particular attention must be given to the polarity of the standard cell, of the battery. and of the voltage, the corresponding + and − signs being marked. If used with a wall galvanometer having a telescope and scale, it will be found convenient to place the potentiometer so that the telescope is directly over the glass index of the slide wire, thus permitting the observer to read the galvanometer deflections and potentiometer settings without changing his position.

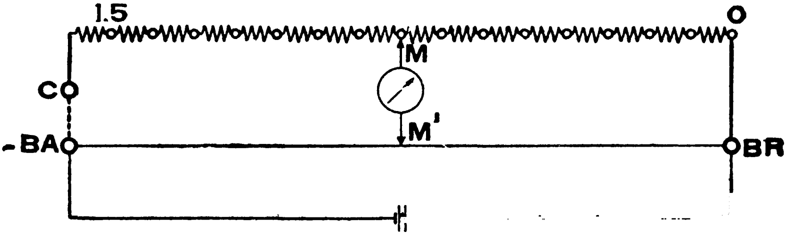


FIG 1,559 —Simplified diagram for checking the slide wire of Leeds and Northrup type K, potentiometer To check the uniformity of the slide wire, connect posts marked BA, and C, by a heavy copper wire, not smaller than No 10 B & S. Post C, will be found between the knobs of the regulating rheostat Place switch S, on E.M.F , and plug P, at 1. Short circuit the E M F, posts, and connect the galvanometer to the GA, posts, and the battery (not in excess of 3 volts) to the posts marked BR and −BA. The slide wire can now be checked against the five ohm coils by the law of the Wheatstone bridge This will be evident from the simplified diagram The contacts M and M′, form one pair of junctions with the galvanometer between, while the posts BR and −BA, form the second pair of junctions with the battery between.

Potentiometer Current.—A storage battery will be found advantageous for producing a steady current in the potentiometer. If a storage battery be not available, two good dry cells, connected in series, will be found satisfactory. The regulating rheostat has been designed to take care of either kind of current source.

Checking Against Standard Cell.—Set the standard cell switch to correspond with the certified *e.m.f.* of the standard cell. Place plug P, in hole 1, and see that it is always* in this position when checking against the standard cell. Place the double throw switch at STD. CELL.

NOTE. ***Exception: See "Measuring voltages from 1.61 to 16.1" on page 1,095.**

Adjust the regulating rheostat until the galvanometer shows no deflection. In making the first adjustment, use the key marked RES.[1], as a balance is more nearly attained, use key RES[2], and for the final balance use key marked O. Key O, gives the maximum sensitivity. To ascertain if the current in the potentiometer circuit alter during a measurement, plug in at 1, throw switch S, to STD. CELL, close the galvanometer key. No deflection indicates that the current has not changed. If the galvanometer deflect, the regulating rheostat must be readjusted.

Measuring Unknown Pressure.—The potentiometer ordinarily is direct reading for voltages up to 1.61 volts. Above 1.61 volts a volt box should be used. However, by means of the method described later, voltages up to 16.1 volts may be measured without a volt box. The method is recommended only in special cases.

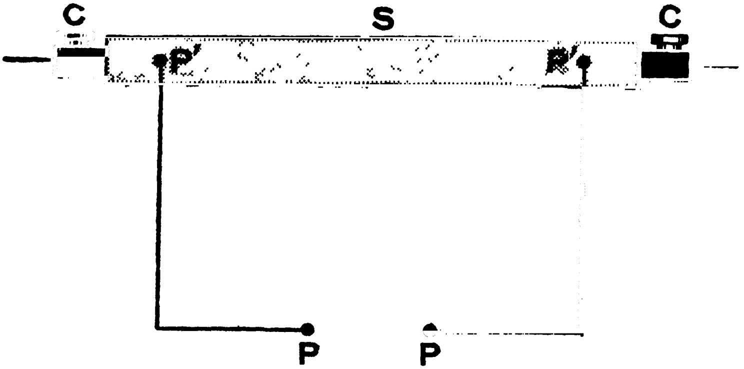


FIG. 1,560.—Measurement of current with Leeds and Northrup type K, potentiometer. This is done by measuring the drop in volts across a known resistance as here shown S, is the standard resistance. and on it are the potential terminals P P', and the current terminals CC The potentiometer is connected to the shunt through the posts marked PP. The resistance between the points P'P , is adjusted to an even value of resistance Most resistances for this purpose are so chosen, that to determine the current passing through the shunt, it is necessary only to multiply the potentiomter reading by a decimal factor. For instance, in using a .01 ohm standard it is necessary to multiply the potentiometer reading by 100, which gives the current reading in amperes, in the same way a .1 ohm requires multiplication by 10, and a .001 ohm by 1,000. The very wide range of this potentiometer, and especially its accuracy in measurement of low pressures, makes it possible to use a resistance standard for a very wide range of current measurements. If the resistance standards for measuring large currents be selected for use with the low range of the potentiometer, they will cost less and be easier to handle than if selected for a high range potentiometer.

After "checking against standard cell" place switch S, on E.M.F. The balance for the unknown pressure is obtained by manipulating dial switch

D, and rotating the contact on the slide wire. The final position of the two contacts in conjunction with the position of plug P, indicates the potentiometer reading. Use key RES^1, for rough adjustment, key RES^2, for intermediate adjustment and key O, for final adjustment.

Plug at 1 or .1.—Plug P, at 1, gives readings directly from the settings of the dial switch and the slide wire contact.

Plug P, at .1 shunts the potentiometer circuit so that the reading is one-tenth of reading taken directly from the scales.

Place plug P, in hole 1 for voltages from .161 to 1.61 volts.

Place plug P, in hole .1 for voltages up to .161 volt.

Example.—A balance was obtained with the dial switch at 1.3 and the slide wire contact at 176 and plug P, at 1. The voltage under test, therefore, is 1.3176. If the plug were at .1 the same reading would have indicated .13176.

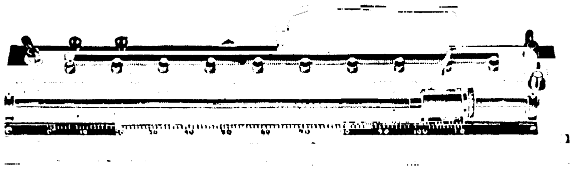


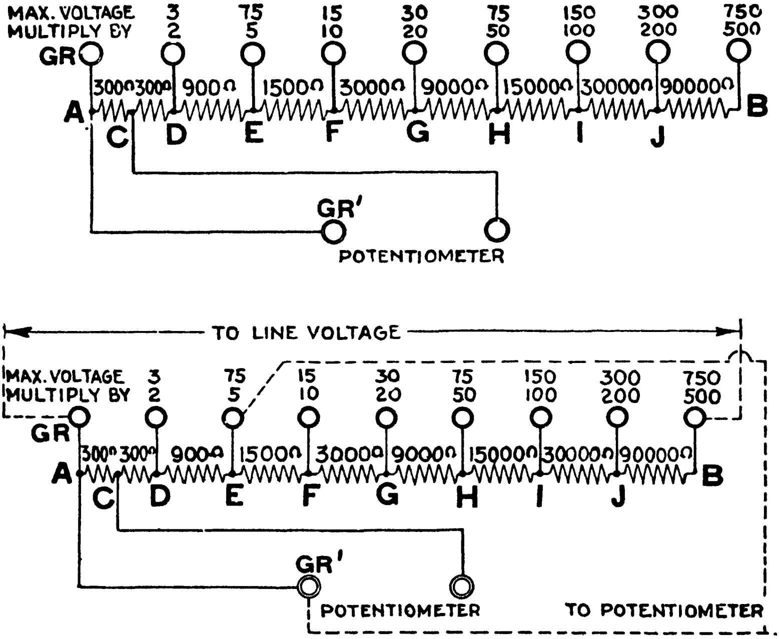
FIG. 1,561.—Leeds and Northrup variable resistance standard. For measurements of resistance less than 1 ohm the Kelvin Bridge provides the most accurate and flexible method. This instrument finds its greatest use in checking or comparing low resistance standards and in the measurement of the conductivity and resistivity of low resistance samples.

Measuring Voltages from 1.61 to 16.1.—Voltages up to 16.1 volts may be measured directly by using a greater voltage across the BA posts. For this purpose a battery of about 20 volts should be used. Insert plug P, at .1 and throw the switch to STD. CELL. Then balance the galvanometer by means of the regulating rheostat. When balanced, insert plug P, at 1, set switch S, on E.M.F. and read the voltage in the usual manner. Multiply the instrument reading by 10.

Use of a Volt Box.—To measure voltages above the direct range of the potentiometer it is necessary to connect the voltage across a high resistance and to measure with the potentiometer a definite fraction of the total voltage. Fig. 1,562 shows the method in diagram, and represents the connections of a volt box.

AB, is a high resistance of which AC, is one five-hundredth; AD, is one-two hundred-fiftieth; AE, is one-hundredth; AF, one-fiftieth, etc. of the total resistance. The potentiometer reading is multiplied by 2, 5, 10, 20 50, 100, 200, or 500, depending upon whether the voltage be connected to AD, AE, AF, AG, AH, AI, AJ, or AB.

Connect the grounded side of the line to the GR, post and the ungrounded side to the post marked with the voltage next higher than the voltage to be measured. Connect the GR¹, post to the potentiometer E.M.F, post of the same polarity as the grounded side of the line, and the other potentiometer post on the volt box to the other E.M.F, post on the potentiometer. Multiply the potentiometer reading by the multiplier as indicated.


MAX. VOLTAGE 3 7.5 15 30 75 150 300 750
MULTIPLY BY 2 5 10 20 50 100 200 500
GR
300Ω 300Ω 900Ω 1500Ω 3000Ω 9000Ω 15000Ω 30000Ω 90000Ω
A
B
C D E F G H I J
GR'
POTENTIOMETER
TO LINE VOLTAGE
TO POTENTIOMETER

FIGS. 1,562 and 1,563.—Method of using a volt box with Leeds and Northrup type K, potentiometer.

With connections as described, maximum sensitivity is obtained and the current drawn from the line never exceeds .005 ampere. For work in which it is desired to draw less than .005 ampere from the line and the sensitivity is sufficient, the ungrounded lead from the potentiometer should be connected to one of the voltage posts as shown by the broken lines in fig. 1,563.

The multiplying factor will then be that at the post connected to the line lead, divided by that at the post connected to the lead from the potentiometer. For example, to measure 110 volts without drawing more than .001 ampere from the line, connect as shown by the broken lines in fig. 1,563, and multiply the potentiometer reading by the ratio of 500 to 5, or 100.

Never apply a higher voltage between the GR, post and any numbered post than the voltage engraved at that post. To do so might seriously damage the volt box.

Care of Potentiometer.—The slide wire, although protected to a great extent by the hood, in time accumulates dust and dirt with a thin film of oxide. This will tend to increase the resistance in this part of the circuit owing to poor contact. This wire should, therefore, be cleaned occasionally.

To do this, unscrew the stop against which the hood strikes when turned to read zero; then remove the hood and rub the entire slide wire vigorously with a soft cloth dipped in vaseline. *Do not use emery or sand paper as this will destroy the uniformity of the slide wire.* Clean also the steel contact which rubs on the wire, as this becomes glazed after much use. When the potentiometer is not in use, the hood should be screwed all the way down, and the lid put in place to exclude dust.

If it be used in a chemical factory, laboratory, or any place where acid fumes are prevalent, this latter precaution is important, because the fumes may attack the slide wire.

It is also well to keep the contact surfaces of the switch studs clean and bright by wiping them occasionally with a soft cloth dipped in vaseline.

Location of Faults Where the Loop Is Composed of Cables of Different Cross Sections.—Faults in loops of this character may be located with the same degree of accuracy as those in loops of a uniform cross section, provided the length and cross section of each length of cable are known. An example will illustrate the method:

In the diagram, fig. 1,565, assume the length of the cable AE to be 550 yards of 25,000 cir. mil., EF, 500 yards of 40,000 cir.

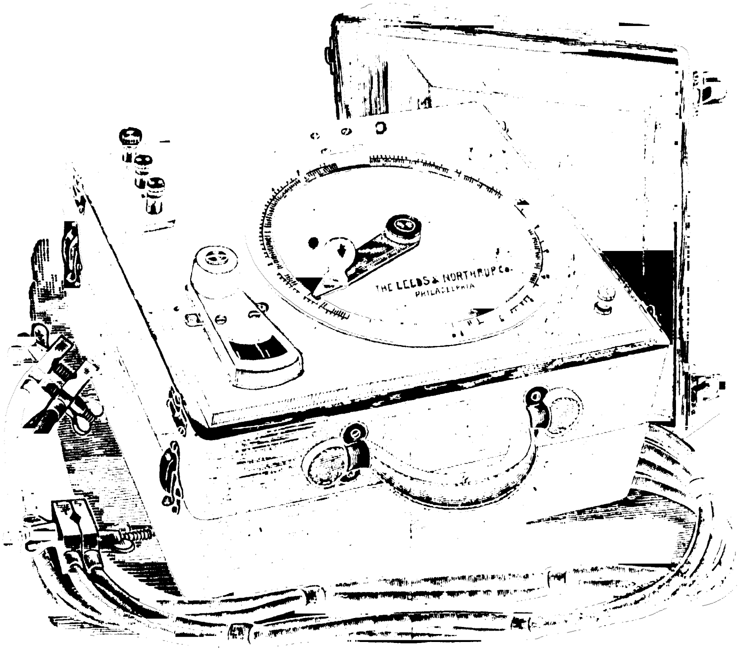
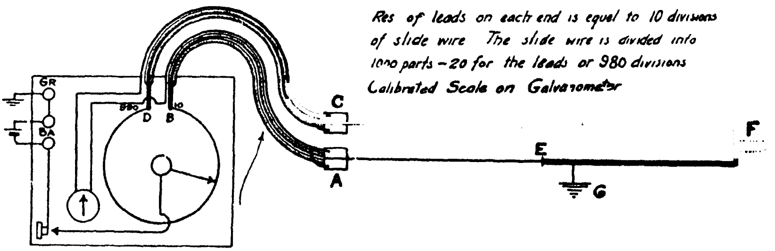


FIG 1,564 —Leeds and Northrup bridge for locating faults in power circuits From the diagram of connections shown in fig 1,565, it will be seen that the instrument operates on the slide wire principle A galvanometer is mounted in the instrument, and the necessary leads for connecting to the cable under test are provided Fault locations are made by means of the Murray loop test Mounted upon a circular block inside the case of the instrument is a low resistance slide wire This wire is made large so that a heavy test current may be used, thus giving a good sensitivity in making locations A sliding contact moves upon the bridge wire and carries with it a pointer moving over a scale on the top of the containing case This scale is divided into 980 divisions, each division being about two millimeters The graduations on the slide wire dial stop ten divisions either side of the ends The end divisions are marked 10 and 990 The resistance of each lead is therefore equal to the resistance corresponding to ten divisions of the slide wire It will thus be seen that the slide wire actually begins at the outer end of the leads, thus entirely eliminating lead resistances mil., and FC, 1,050 yards of 30,000 cir. mil. These lengths must be reduced by calculation to equivalent lengths of one size, and for this purpose it is best to select the largest size. The results of this calculation are as follows:

550 yds. of 25,000 cir. mil. = 880 yds. of 40,000 cir. mil.
500 " " 40,000 " " = 500 " " 40,000 " "
1,050 " " 30,000 " " = 1,400 " " 40,000 " "

This makes the total resistance of the loop equivalent to



Res of leads on each end is equal to 10 divisions of slide wire The slide wire is divided into 1000 parts – 20 for the leads or 980 divisions Calibrated Scale on Galvanometer

FIG. 1,565 —Diagram of Leeds and Northrup bridge for locating faults in power circuits, showing arrangement of the connections including the lead cables and galvanometer contacts. Make connections as shown. The clamps must be so fastened at A and C, that the contact resistances will be very small This contact resistance will figure in as an error in the measurement If, for instance, the contact resistance were equal to .001 of an ohm, and the wire were of such a size that .001 of an ohm were equal to the resistance of 20 feet of the cable, there would be an error of 20 feet in the location of the fault. For this reason all contact resistances throughout the loop from A to C, must be extremely small. The battery is to be connected to the posts marked Ba, and the post marked Gr, is to be grounded. It will very frequently happen that the ground is to the cable sheath or some other conductor. In this case, the binding post Gr, should be grounded to this conductor. Sufficient battery should be used to give a readable deflection on the galvanometer for a small movement of the contact on the bridge wire. The fault is located by the usual Murray formula. If, for instance, the galvanometer show no deflection when the contact is at 300 on the scale, it would indicate that the fault is at a distance from A, equal to .003 of the total length of the loop from A to C. A testing current of five amperes may be used with this bridge. In cases of necessity, this current may be increased to eight amperes, but when this current is used it should not be allowed to pass through the bridge for a longer time than is necessary. It frequently happens that small faults which have a very high resistance develop in high pressure cables. Such faults are likely to break down and result in damage and should be located. It is usually impossible to locate these faults until they have been partially carbonized. This must be done by applying a sufficiently high voltage between the cable and the sheath (or whatever it is grounded on) to break down the fault. In order to prevent the breaking down process resulting in a serious burn out, a high resistance must be placed in the circuit which will prevent an excessive current, or the circuit must be carefully fused The former procedure is the better

2,780 yards of 40,000 cir. mil. If the contact show a balance for a reading of 372.5, this indicates that the fault is at a distance of $\frac{372.5}{1,000}$ of 2,780 = 1,035.5 equivalent yards. Of this, 880 are in the stretch AE. Consequently the fault is:

$$1,035.5 - 880 = 155.5 \text{ yards from E.}$$

Insulation and the Measurement of its Resistance.—All electrical insulating materials have two fundamental electrical properties:

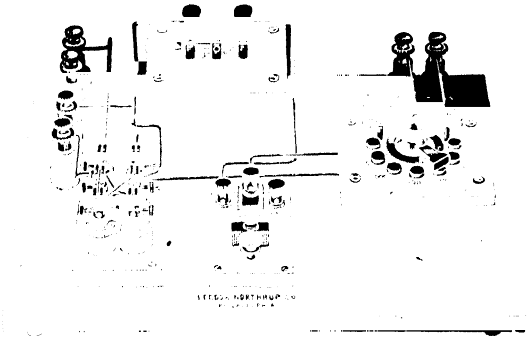


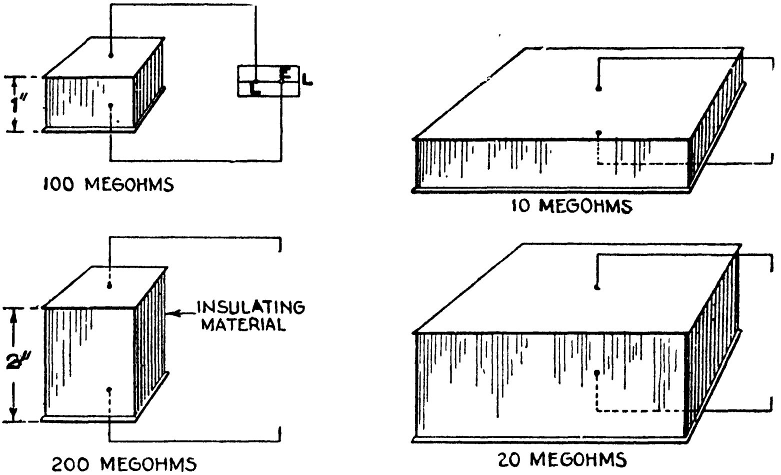
FIG. 1,566.—Leeds and Northrup insulation testing set. Wherever cable testing apparatus is to be permanently set up and used in a laboratory or test room a desirable combination consists of an outfit made up of the individual instruments mounted so as to secure ample insulation, and so wired that the connections may be easily traced. The set here shown is for insulation testing, and includes all necessary instruments for this work. The galvanometer and lamp and scale, however, are not shown. The best insulation is secured by mounting all the instruments, with the exception of the galvanometer and lamp and scale, upon a substantial hard rubber plate. The connections are made by heavy enameled wires run in air and held in place by hard rubber posts, petticoat insulated. All switches and keys are of substantial construction and are so arranged that they may be conveniently operated.

1. Insulation resistance; and
2. Dielectric strength.

By definition, *insulation resistance* is *the opposition to the passage of current*, and *dielectric strength* is *the strength against breakdown under static or high voltage stress.*

Insulation resistance is expressed in ohms or megohms (millions of ohms) and is proportional to *the thickness of a homogeneous insulating material* and inversely proportional to *the area under test.*

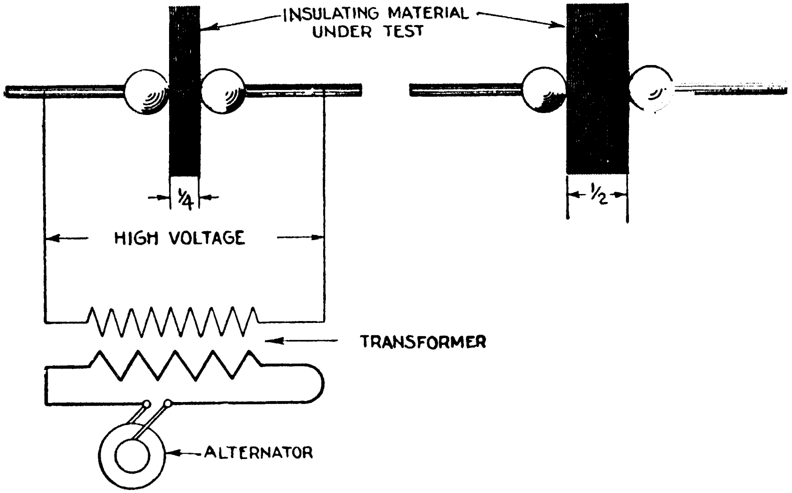
Thus if a sheet of such material on each side of which is a metallic conductor be in perfect contact over the whole area, the insulation resistance might be 100 megohms. Now if the sheet and metallic conductors be extended to ten times the area, the insulation resistance will be only 10 megohms, see figs. 1,567 and 1,568. This illustrates why the insulation resistance of a short length of good wire or cable, for example, is higher than that of a greater length of the same conductor under similar conditions. On the other hand, if the thickness of the insulating material mentioned above be doubled, the insulation resistance becomes 200 megohms and 20 megohms respectively.



FIGS. 1,567 to 1,570.—Diagrams showing how insulation resistance is theoretically "proportional to the thickness of a material and inversely proportional to the area under test."

Dielectric strength as it is ordinarily conceived, is expressed *in terms of the voltage at which insulation punctures or fails at* *some point due to static stress.** It is not affected by the area of a homogeneous insulating material, but does increase with increased thickness, as shown in figs. 1,571 and 1,572.

Dielectric strength can be measured only by testing to failure,—similar in principle to the way samples of building material are tested to destruction.



FIGS. 1,571 and 1,572.—Diagram showing that dielectric strength increases with increased thickness of the insulating material.

It must be clearly understood that the two properties—*insulation resistance* and *dielectric strength*, are entirely distinct and separate, and that both are important.

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*NOTE.—***Current through a resistance** causes heat, if this heat be not dissipated it causes a reduction in the resistance of the insulating material (the temperature co-efficient of insulating materials being negative and numerically large) this causes further heating and increased current which then rapidly proceeds to *failure* at that particular point. Therefore ***true dielectric strength*** is "*the critical voltage at and above which the increase of temperature in the insulating material increases the current density and the temperature indefinitely*, thereby short circuiting the applied potential and destroying the insulator. Below this critical voltage the conditions are stable and the insulator is good."

Up to the present time no simple relation between the two has been found. Insulation resistance cannot be taken as a measure of the voltage required to cause a breakdown or puncture of the insulation, but it is a valuable *guide* in this respect.

Many engineers find it wise to make insulation resistance tests during manufacture and after repairs, *before* applying the high voltage test, in order, as far as possible, to avoid unnecessary breakdown. Also, it has been found that, under certain conditions, the insulation resistance of electrical apparatus will decrease owing to the application of high voltage even though dielectric breakdown did not occur. This is entirely in addition to the apparent reduction in dielectric strength itself which occurs when the high voltage test is prolonged.

FIG 1,573.—Testing armatures with Biddle "Meg" insulation tester in an electrical repair shop.

There is no way in which the high voltage dielectric test can indicate low insulation resistance without causing failure.

If the insulation break down, it only indicates that the insulation was weak at the particular point where breakdown occurred. Furthermore, high voltage testing does subject electrical equipment to serious risk of unnecessary and permanent injury. particularly old equipment where the application of high voltage is "playing with fire" as far as trouble is concerned.

By the insulation resistance test, the condition of a piece of electrical apparatus can be determined. If the insulation of a dynamo, motor or cable contain moisture, or is deteriorated, a so called high voltage breakdown is liable not to be a dielectric point or points of the poor insulation.

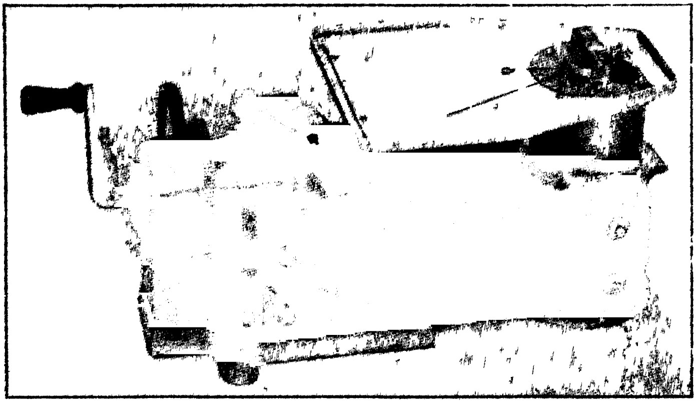

Fig 1,574.—Biddle Megger testing set with case removed showing construction. One quarter size.

Thus the insulation is completely and permanently injured by the high voltage current, whereas an insulation resistance test would show, without risk of injury, whether the machine or cable was in condition safe for continued operation. Many a high voltage failure has been due to nothing more than that.

In all low voltage apparatus, static strains are so small that they need not be considered. In high voltage apparatus, the static strains become very important, but not more important than resistance to the leakage of current. In all apparatus, insulation must be planned to be safe against failure either way.

Leaky insulation is liable to have the defect at some particular point however, hard it may be to locate or positively determine it. Through this defect a small leakage of current flows.

By reason of electrolytic action, or a local rise of temperature, or both, the resistance decreases and more current flows. This may go on, accompanied by slight charring, which further decreases the resistance, allowing still more current to flow. The effect is cumulative, so that at last a real burn out may occur, caused by a large flow of current through what was at first a very small leak.

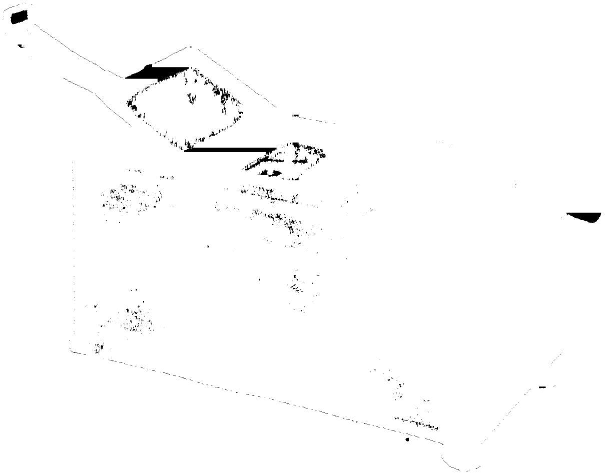

FIG. 1,575.—A high range "Megger" testing set ready for use

On an over voltage test, an increased leakage of current flows as the result of the high voltage, and thus in the same way a breakdown may be produced in a few seconds, which in normal operation would have occurred only after a long time, or perhaps not at all. In fact, if a leak be due to moisture, dirt or any other transient condition, or is local in some particular part of the apparatus, a breakdown need not occur; for a measurement of insulation resistance will show that the conditions are not safe for the operation of the apparatus, much less for the application of over voltage. Under these conditions the source of the trouble should be sought, and in many instances can be located and easily remedied.

The high voltage test is not a measure of the condition of the insulation; the insulation resistance test is such a measure.

If no local condition can be found it may be concluded that the leak causing the low insulation resistance is distributed through the insulation; in such cases, the apparatus may be considered all right, providing the insulation resistance do not fluctuate widely with operating conditions nor show a definite falling off as time goes on. Therefore, an insulation resistance test should be made in advance of the dielectric test as a means of guarding against failure due to leaks while subject to high voltage. It should be repeated after such a test in order to make sure that the insulation has not been permanently weakened by the application of high voltage.

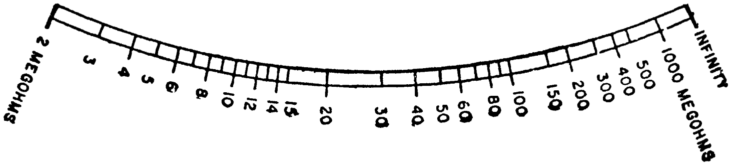

Fig. 1,576.—Scale of Biddle high range *Megger* testing set. With the "L" ratio switch this scale may be divided by 10 and by 100, so that it may have the additional ranges of 200,000 ohms to 100 megohms and 20,000 ohms to 10 megohms.

Surface leakage, while not a defect of the insulating material, a surface leakage path through oil, dirt, metallic dust or moisture from an exposed conductor to ground, or between conductors, may lead to a "flash over" and serious damage to the apparatus.

Wiping off a machine is no guarantee that such paths have been eliminated. Tests of insulation resistance will reveal their presence. In most tests nothing is known of the exact area or thickness of the insulation, while it is certain that it is not perfectly homogeneous and the conductors may not be in perfect contact with its entire surface. Also, there may be surface leakage paths. Therefore, when any particular value is noted on making a test, it is impossible to know whether it be due to general characteristics or to some local defect.

If the resistance be too low for safe operation, the cause should be sought, it may be due to moisture or even dirt, and remedied if possible.

Often by separating connections, the location of a real leak due to a defect in the insulation can be determined and repairs made.

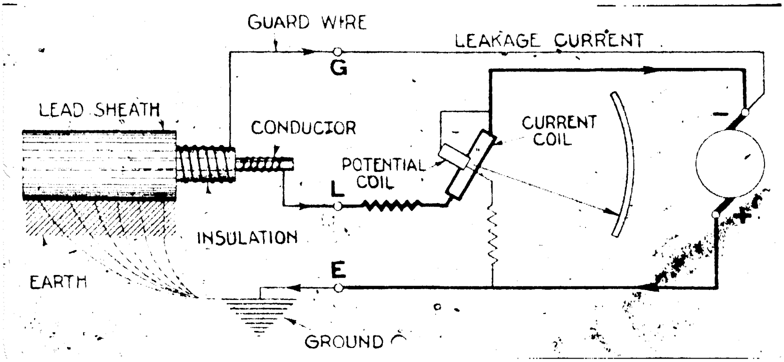

FIG 1,577 —Schematic diagram showing how the effects of surface leakage on apparatus under test may be eliminated by the extension of the guard system from the guard terminal of a high range "Megger" testing set.

On the other hand, if the insulation resistance be sufficiently high to permit operation, its value may increase as time goes on, particularly if at the beginning the apparatus were not thoroughly dry. However, if a leak even of very high resistance, due to a local defect in the insulation, be present, there is a possibility that it may gradually decrease in resistance until finally it results in a breakdown.

The insulation resistance test preceding the high voltage test determines to a large extent whether the insulation be likely to break down under the application of high voltage.

Very often it occurs that moisture has gotten in or there exist paths for leakage which should be dried out or removed before applying the high voltage. Thus to a great extent, unnecessary breakdown can be prevented.

The insulation resistance test following the high voltage test is the only method known for determining whether the high voltage has injured apparatus which otherwise did not show an actual breakdown when the high voltage was applied. It is well known that the application of high voltage may weaken insulation without causing failure.

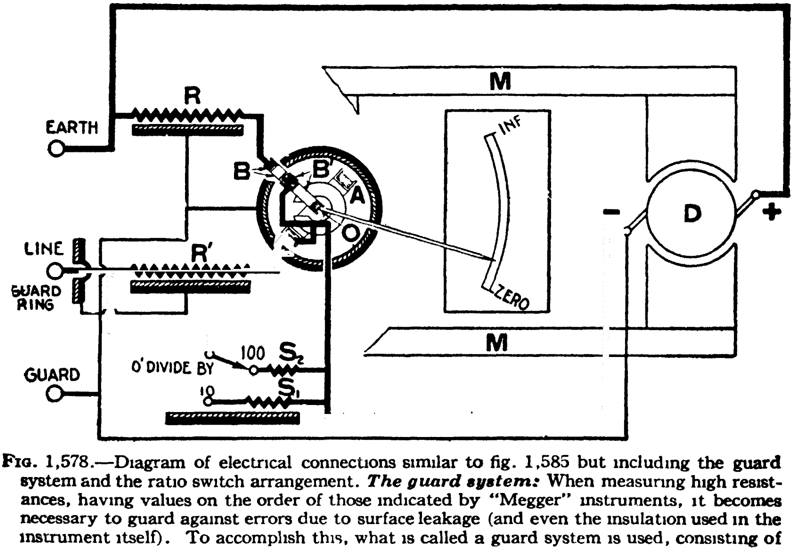

FIG. 1,578.—Diagram of electrical connections similar to fig. 1,585 but including the guard system and the ratio switch arrangement. ***The guard system:*** When measuring high resistances, having values on the order of those indicated by "Megger" instruments, it becomes necessary to guard against errors due to surface leakage (and even the insulation used in the instrument itself). To accomplish this, what is called a guard system is used, consisting of hard rubber bushings, mica and other insulating materials ***In operation,*** current may leak over the surface of the case from the positive earth terminal toward the negative line terminal, but as soon as it reaches the guard ring, it is carried back directly to the negative side of the dynamo or applied voltage. As the leakage current is thus unable to flow into the line terminal and on through the moving element, it cannot affect the indication on the scale.

If the insulation resistance be low, separate the various connections of the apparatus and test each part separately, in an endeavor to locate and remedy the trouble.

For instance, in a *d. c.* motor or dynamo, lift the brushes and separate the connections to brush holders and field. Test armature, brush holders

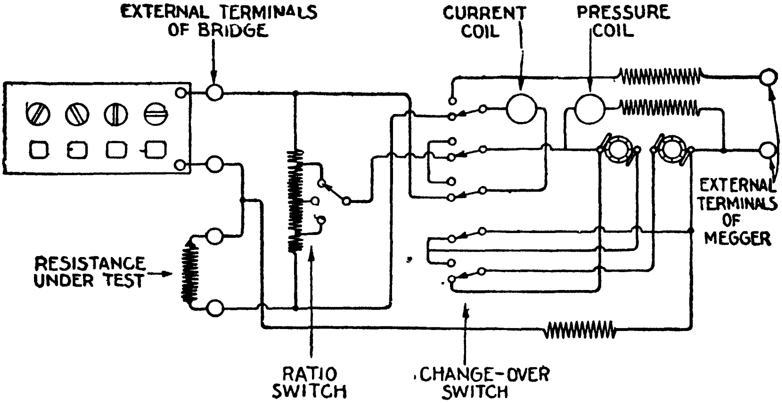

FIG. 1,579—Diagram of internal connections of Biddle "Megger" testing set. The change over switch is shown set to "Bridge." As the name implies the set combines the functions of a Wheatstone bridge and a "Megger" testing set When working as a "Bridge" pressure is supplied by the hand magneto, the current coil of the ohm meter acts as a galvanometer and an auxiliary dial resistance box is used for direct comparison with the resistance under test, using the ratios 1 to 1, 1 to 10, or 1 to 100 as needed. By interchanging the resistance box with the resistance under test (see fig. 1,583) the ratios become 1 to 1, 10 to 1 or 100 to 1. The principle of operation is identically the same as that of any Wheatstone bridge

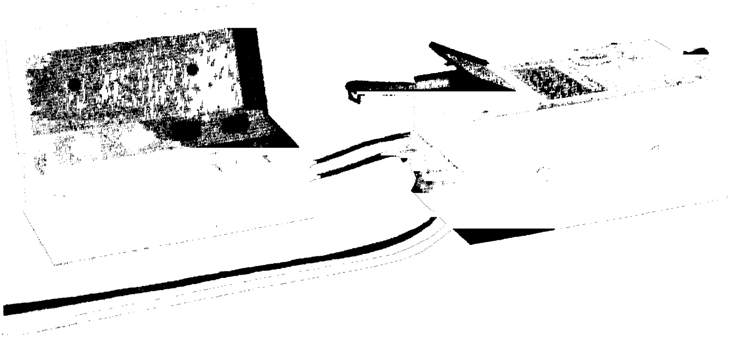

FIG. 1,580.—Biddle Bridge-Megger testing set with direct reading resistance box connected ready for use.

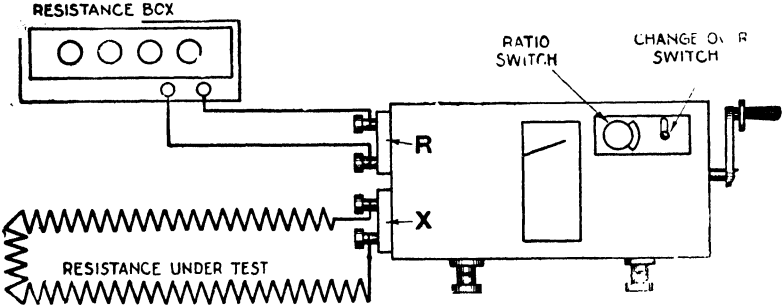

FIG. 1,581.—External connections for Bridge Megger measurements under 10,000 ohms.

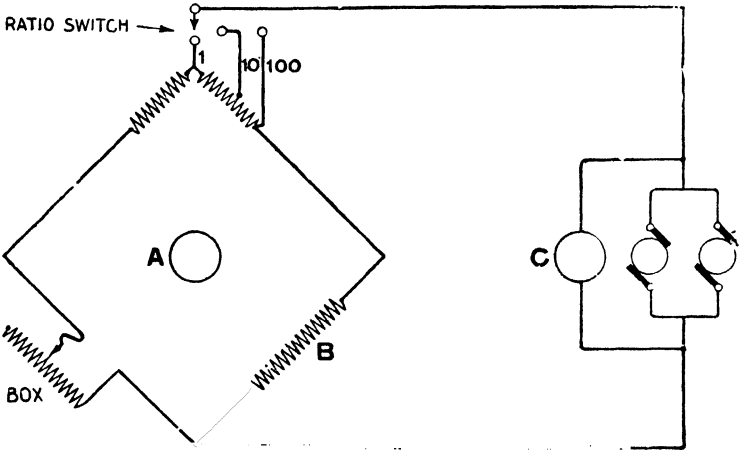

FIG. 1,582.—Internal connections for bridge measurements under 10,000 ohms. A current coil used as galvanometer coil; B, resistance to be measured; C, pressure coil used as control coil.

NOTE.—***Starting the "Megger" method.*** In starting the "Megger" method of electrical maintenance, particularly on motors, wiring, etc., in industrial plants, it may be found difficult to secure and maintain the *one megohm standard*. But conditions can be improved gradually as time permits workmen to clean parts, renew deteriorated insulation, dry out moisture, etc., so that a higher working standard can be arrived at after a reasonable time. Those who maintain the equivalent of the one megohm standard find from experience that if the insulation resistance of their equipment be up to such values, troubles are so much less likely to occur that results are worth far more than the effort and expense involved in making the tests.

and field. If necessary, test each brush holder and field coil separately. The trouble may be due to nothing more than moisture or "green" insulation, in which case the apparatus should be dried out or baked until the insulation resistance becomes constant at a reasonable value. Bear in mind that the insulation resistance of a completely connected machine or piece of apparatus is less than the insulation resistance of any of the separate parts.

Regulations for insulation resistance by the American Institute of Electrical Engineers and also by the Underwriters Laboratories, indicate what may be called "code" rules for minimum values of insulation resistance, below which there is felt to be imminent danger of failure of the apparatus.

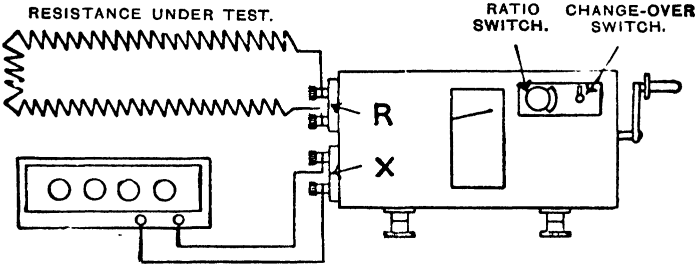

FIG. 1,583.—External connections for Bridge "Megger" measurements over 10,000 ohms.

In actual practice, readings much higher than these usually are found on electrical equipment both new and old. From a study of results obtained by a larger number of "Megger" users, it is observed that in general an insulation resistance of one megohm is considered a fair allowable lower limit on the ordinary run of electrical apparatus, such as motors, dynamos, rotary converters, power cables and wiring, etc. There are exceptions of course, such as large machines and long cables where readings lower than one megohm may be considered entirely satisfactory.

High tension transformers and similar equipment, if not oil immersed, usually have much higher insulation resistance.

NOTE.—With insulation resistance of one megohm it is reasonably certain that there are no serious surface leaks and also that power apparatus, at least, is *reasonably* dry.

Principle of operation of "Megger" testing set.—The "Megger" insulation testing and high resistance measuring instrument consists essentially of a direct reading true ohm meter of the permanent magnet, moving coil type mounted in a suitable case with a hand driven magneto or provided with other means for supplying *d.c.* voltage for the test.

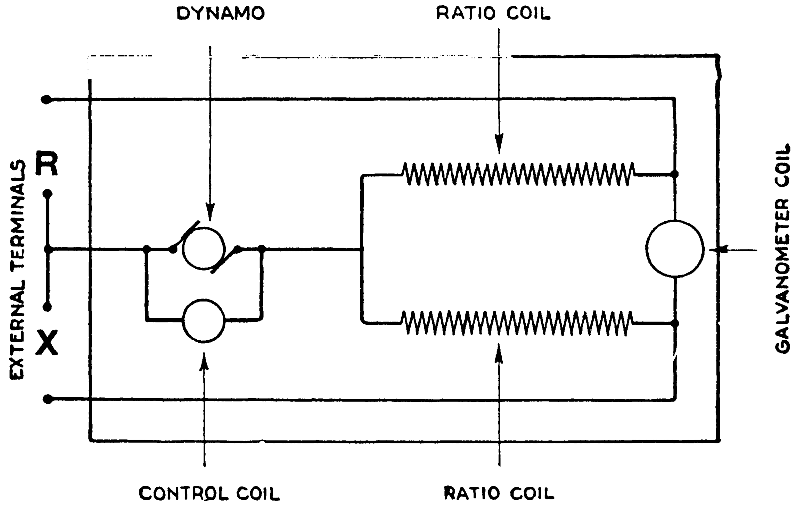

Fig. 1,584.—Internal connections for Bridge "Megger" measurements showing actual connections to terminals R and X.

The diagram fig. 1,585 shows the essential magnetic circuit and electrical connections. M and M, are permanent bar magnets. Between the poles at one end is the armature D, of the hand driven dynamo and between the poles at the other end is the moving system of the true ohm meter.

In the "Megger" and "Meg" ohm meters, the hand magneto is omitted and an external *d.c.* voltage is used, see fig. 1,586.

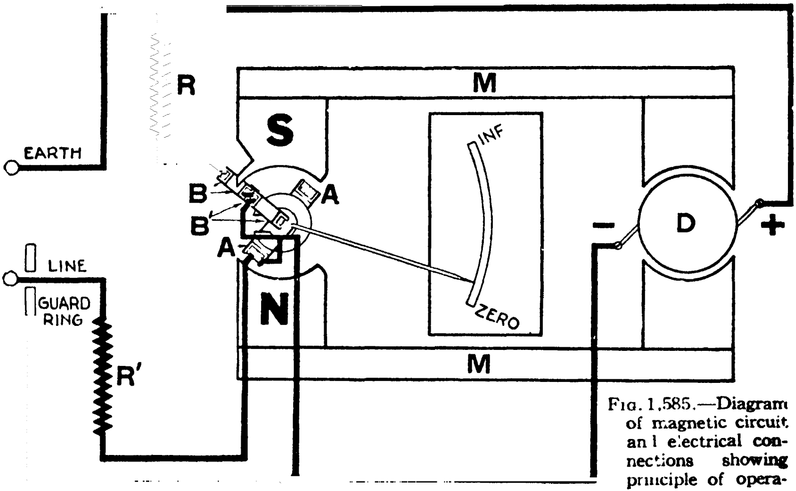

Fig. 1,585.—Diagram of magnetic circuit and electrical connections showing principle of operation of Biddle "Megger" insulation testing and high resistance measuring instruments.

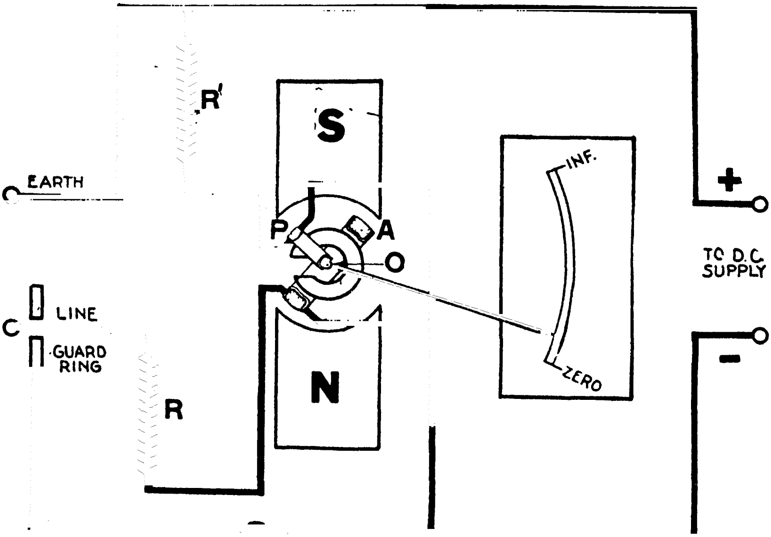

Fig. 1,586.—Diagram of electrical connections showing principle of operation of "Meg" and "Megger" ohm meters.

The ohm meter has three coils; A, B and B′ (see figs. 1,585 and 1,587) fixed rigidly together and free to rotate about the axis 0.

There are no controlling springs, but current is led to the coils by flexible copper ligaments having the least possible torsion, so that the pointer "floats" over the scale when the dynamo is not being operated.

Coils B and B′, are connected in series through the resistance R, across the generated voltage; they constitute the "control" element of the ohm meter and give the instrument the property of indicating correctly irrespective of the exact value of the voltage generated or supplied, or the strength of the permanent magnets. These coils are so connected that when voltage is applied they tend to turn the axis in counter clockwise direction until they assume a position where their rate of cutting the magnetic flux is zero, that is, directly opposite the gap in the C, shaped iron core about which B′, moves. The pointer then indicates infinity on the

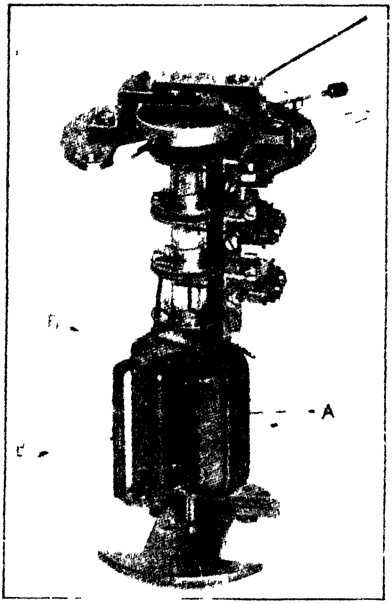

FIG. 1,587.—Moving system of Biddle Megger testing set scale. This is what happens when a "Megger" instrument is operated with nothing connected across the terminals Earth and Line.

The moving coil A, which is always in a uniform radial magnetic field, receives current from the magneto through the resistance coil and the unknown resistance connected to the terminals Earth and Line. The electrical connections are such that this current tends to turn the axis in a clockwise direction, in opposition to that of B and B′.

When the Earth and Line terminals are short circuited the torque produced by A, overpowers that of B and B′, and the pointer stands over the point marked Zero. If now a suitable resistance be connected to the external terminals, the current from the magneto has two paths available and will divide, part passing through the "control" coils B and B′, and part through coil A, in series with the resistance under test. The result is that the opposing torques of the two elements balance one another at a point on the scale corresponding to the value of the resistance connected. In this way, by using various values of resistance, the entire scale is calibrated.

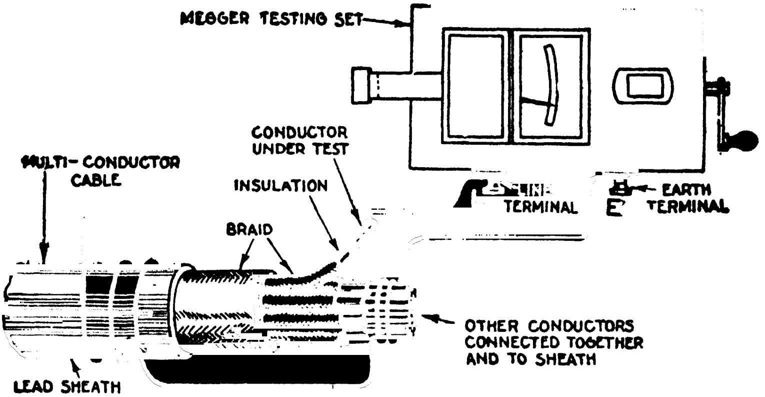

FIG. 1,538.—Method of testing each wire of a multi-conductor cable with Biddle "Megger" testing set. ***Select*** about fifteen or twenty wires at random in the particular bunch under test and test each one against all other wires in that bunch. Repeat for each bunch of wires. If all the wires in the cable test clear, make the remaining splices. When a number of tests of this kind are to be made, it is convenient to use a motor driven "Megger" testing set.

Because the two elements of the ohm meter are supplied from the same source of voltage, the pointer will always move to the same position for a given resistance under test.

Any change of magneto or applied voltage affects both circuits in the same proportion. Similarly the strength of the permanent magnets can vary considerably without affecting the accuracy of the instrument.

TEST QUESTIONS

1. *What error is introduced in measuring the pressure of a battery with an ordinary volt meter?*
2. *Define the International volt.*
3. *What is the standard of current measurement?*
4. *What is a volt meter?*
5. *Upon what do the various tests made by the practical electrician depend?*
6. *Define the International ohm.*
7. *Name and explain seven methods of measuring resistance.*
8. *Upon what is the direct deflection method based?*
9. *Describe a resistance box.*
10. *What method of measuring resistance is used in electrical stations?*
11. *What is the drop method used for?*
12. *Describe the so called Wheatstone bridge, and explain its use.*
13. *What is the decade plan?*
14. *What is a testing set?*
15. *What is a loop test?*
16. *Describe the Murray loop, Varley loop and special loop tests.*
17. *What are the various loop tests used for?*
18. *Describe the Kelvin bridge and its use.*

19. *What is a reversible slide wire bridge used for?*
20. *Describe the test for location of opens.*
21. *Describe the tests for telegraph and other multiple cables.*
22. *Give the method of picking out a grounded wire.*
23. *What kind of test is the Varley loop specially used for?*
24. *Give some notes on the Varley test.*
25. *Describe the direct reading ohm meter.*
26. *What is a potentiometer?*
27. *Explain the principle of the potentiometer.*
28. *Name three classes of potentiometers.*
29. *Describe a slide wire bridge.*
30. *How is the voltage of a cell measured with the potentiometer?*
31. *How is a volt box used with a potentiometer?*
32. *Describe the location of faults where the loop is composed of cables of different cross sections.*
33. *Name two properties of insulating materials.*
34. *What may result from surface leakage?*
35. *Describe the instruments used for insulation testing.*
36. *Name two fundamental electrical properties of all insulating materials.*
37. *Define insulation resistance.*
38. *What is dielectric strength?*
39. *How is dielectric strength measured?*
40. *What is the effect of current flowing through a resistance?*
41. *What is the characteristic of leaky insulation?*

42. *Does a high voltage test measure the condition of insulation?*
43. *What sometimes results from surface leakage?*
44. *What insulation resistance regulations are given in the Code?*
45. *Give the principle of operation of "Megger" testing set.*
46. *Describe other instruments used in insulation testing.*

CHAPTER 40

Storage Batteries

Introduction.—The practical development of the storage battery is comparatively recent, although a knowledge of the phenomena upon which its actions are based, dates back to 1801. In 1800, the year made memorable by Volta's discovery of the galvanic battery, Nicholson and Carlisle found that a current from Volta's cell could decompose water.

NOTE —***In 1801, Gautherot*** discovered that if two plates of platinum or silver, immersed in a suitable electrolyte, be connected to the terminals of an active primary cell and current be allowed to flow, a small current could be obtained on an outside circuit connecting these two electrodes as soon as the primary battery had been disconnected

NOTE—***Erman found*** that the positive pole of such a cell, was the pole which had been connected to the positive pole of the battery.

NOTE —***In 1803,*** Ritter observed, with gold wire, the same phenomenon as Gautherot, and constructed the first secondary battery, by superposing plates of gold, separated by cloth discs, moistened with ammonia

NOTE —***Volta, Davy, Marianini,*** and others added somewhat to the knowledge on the subject, and in 1837, Schoenbein found that peroxide of lead could be used in secondary batteries

NOTE —***Sir William Grove*** next came forward with the discovery that metal plates, with a layer of oxide on them, acted better than the plain metallic plates, and Wheatstone and Siemens found still later that peroxide of lead was the best for such purposes

NOTE —***In 1842, Grove*** constructed a gas battery, in which the force came from the oxygen and hydrogen evolved in the electrolysis of water acidulated with sulphuric acid. By means of fifty such cells, he obtained an arc light.

NOTE —***Michael Faraday,*** when electrolyzing a solution of lead acetate, found that peroxide was produced at the positive, and metallic lead at the negative pole, and in his "Experimental Researches," he comments on the high conductivity of lead peroxide, and its power of readily giving up its oxygen Although he made no apparent use of this discovery, it may be considered as the next important step in the development of the storage battery.

As to the theory at this time, it may be stated that Clerk Maxwell, although the leading electrician of his time, speaks of the storage battery as storing up a quantity of energy in a manner somewhat analogous to the ordinary condenser, hence the use of the word "accumulator" for storage battery.

Ques. To what use is the storage battery sometimes put in electric lighting or power stations?

Ans. To carry the "peak" of the load, and the entire load

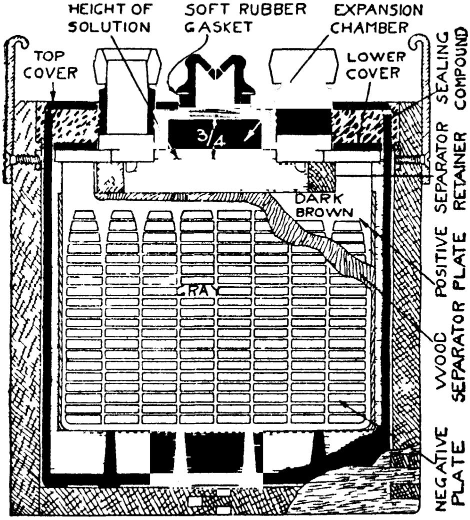

FIG. 1,589 —Sectional view of Gould cell showing various parts

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NOTE —***According to Niblett, Wheatstone, de la Rue and Niaudet*** were well aware that peroxide of lead was a powerful depolarizer, but nobody appears to have made use of this fact until 1860, when M Gaston Plante constructed his well known cell with coiled plates Plante's researches extended up to 1879, and practically determined the state of the art

NOTE —***In the manufacture*** of storage battery plates, nearly every conceivable shape has been tried, and it has been found that an approximately square plate gives the best results The plate should not be made too deep, else it will be subjected to different degrees of chemical action The plate should be so constructed as to be able to expand with the active material, without destroying the contact between the two The electrolyte should have free access to all parts of the active material at minimum hours. To act as equalizer or reservoir. Also for equipment of annex or substations.

Theory of the Storage Battery.—The action of the storage battery is practically the same as that of the primary battery and it is subject to the same general laws. The cells of a storage battery are connected in the same way as primary cells, and when charged is capable of generating a current of electricity in a manner similar to that of a primary battery.

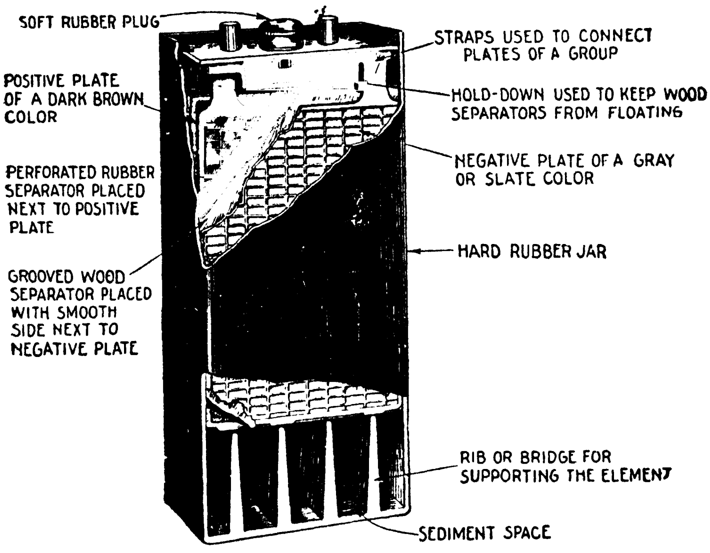

SOFT RUBBER PLUG
POSITIVE PLATE OF A DARK BROWN COLOR
PERFORATED RUBBER SEPARATOR PLACED NEXT TO POSITIVE PLATE
GROOVED WOOD SEPARATOR PLACED WITH SMOOTH SIDE NEXT TO NEGATIVE PLATE
STRAPS USED TO CONNECT PLATES OF A GROUP
HOLD-DOWN USED TO KEEP WOOD SEPARATORS FROM FLOATING
NEGATIVE PLATE OF A GRAY OR SLATE COLOR
HARD RUBBER JAR
RIB OR BRIDGE FOR SUPPORTING THE ELEMENT
SEDIMENT SPACE

FIG. 1,590.—Sectional view of Exide cell in rubber jar showing various parts. The positive plates when burned to the strap as shown, are called the positive group. The negative plates, when burned to the strap as shown, are called the negative group. Both groups and separators assembled as shown, are called the element.

NOTE.—***In 1879, R. L. Metzer*** did away with the tedious forming process. by mechanically applying the active material. This important discovery was not, however, generally known, until 1881, when Camille Faure obtained important patents concerning the method of shortening the time of formation.

NOTE.—***Charles F. Brush,*** working independently of either Faure or Metzer, arrived at the same result, and the United States courts have decided after long litigation, that to him belongs the priority of invention in this country.

It differs, however, from the primary battery in that it is capable of being recharged after exhaustion by passing an electric current through it in a direction opposite to that of the current on discharge. This difference constitutes the principal advantage of the storage battery over the primary battery.

Ques. Describe a storage cell.

Ans. It consists of plates or of grids in an electrolyte of such a character that the electrical energy supplied to it is converted into chemical energy (a process called charging). The chemical energy can be reconverted into electrical energy (a process called discharging).

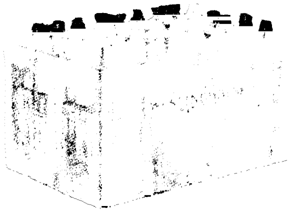


Fig. 1,591.—Westinghouse 12 compartment glass case radio storage B battery. 24 volts; capacity 3,500 milliampere hours (3.5 ampere hours) when discharged at a rate of 40 milliamperes. The clear glass case gives the user a view of the action of the battery on charge and discharge, and permits a ready inspection of plates and separators as well as the level of the acid solution. A layer of sealing compound over the rubber covers and around the posts keeps this battery free from acid leakage.

Ques. Describe the electrolyte generally used.

Ans. It consists of a weak solution of sulphuric acid which permits ready conduction of the current from the charging source; the greater the proportion of acid within certain limits, the smaller the resistance offered.

Ques. What is the effect of the current passing through the electrolyte?

Ans. It decomposes the water into oxygen and hydrogen;

this is indicated by the formation of bubbles upon the exposed surfaces of both plates, these bubbles being formed by oxygen gas on the plate connected to the positive pole of the primary battery, and hydrogen on the plate connected to the negative pole.

Because, however, the oxygen is unable to attack either platinum or silver under such conditions, the capacity of such a device to act as an electrical accumulator is practically limited to the point at which both plates are covered with bubbles. After this point the gases will begin to escape into the atmosphere.

Ques. What is the prime condition for operation of a storage battery?

Ans. The resistance of the electrolyte should be as low as possible in order that the current may pass freely and with full effect between the electrodes.

If the resistance of the electrolyte be too small, the intensity of the current will cause the water to boil rather than to occasion the electrolytic effects noted above.

Ques. What happens when the charging current is discontinued, and the two electrodes joined by an outside wire?

Ans. A small current will flow through the outside circuit, being due to the recomposition of the acid and water solution. The process is in a very definite sense a reversal of that by which the current is generated in a primary cell.

Hydrogen collected upon the negative plate, which was the cathode, so long as the primary battery was in circuit, is given off to the liquid immediately surrounding it, uniting with its particles of oxygen and causing the hydrogen, in combination with them, to unite with the particles of oxygen next adjacent. The process is continued until the opposite positive plate is reached, when the oxygen collected there is finally combined with the surplus hydrogen, going to it from the surrounding solution.

This chemical process causes the current to emerge from the positive plate, which was the anode, so long as the primary battery was in circuit. The current thus produced will continue until the recomposition of the gases is complete; then ceasing because these gases, as before stated, do not combine with the metal of the electrodes.

Types of Storage Battery.—There are three general classes of storage cell classified according to the type of plates.

1. Plante cells;

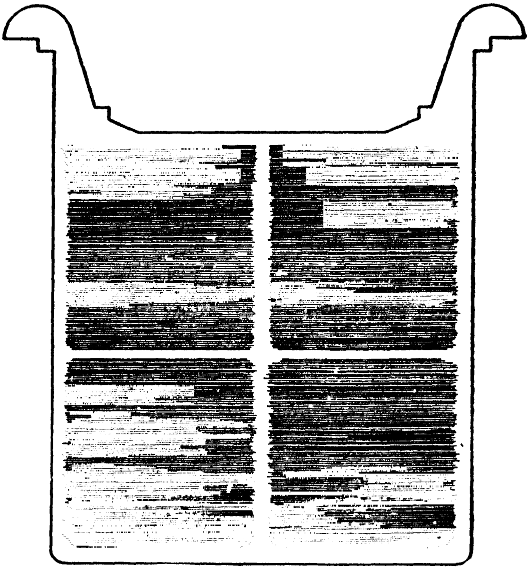


FIG. 1,592.—Unformed Plante type plate, showing appearance of plate before forming. The clear outline of the grooves indicates absence of oxide, due to action of "forming" solutions, or charging current.

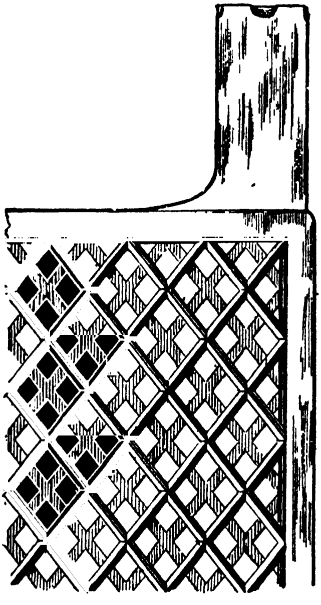
2. Faure cells;
3. Manchester cells.

According to construction secondary cells may be classified as follows:

1. Lead sulphuric acid cells;
2. Lead copper cells;
3. Lead zinc cells:
4. Alkaline zincate cells.

The lead sulphuric acid type includes all those cells belonging to the Plante and Faure groups.

Lead copper cells consist of sheets of metal coated with lead oxide, serving as the positive electrode, and copper plates for the negative



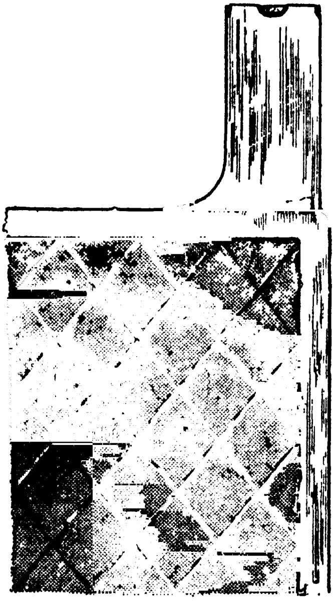


Fig. 1,593.—Faure or pasted type plate grid without active material.

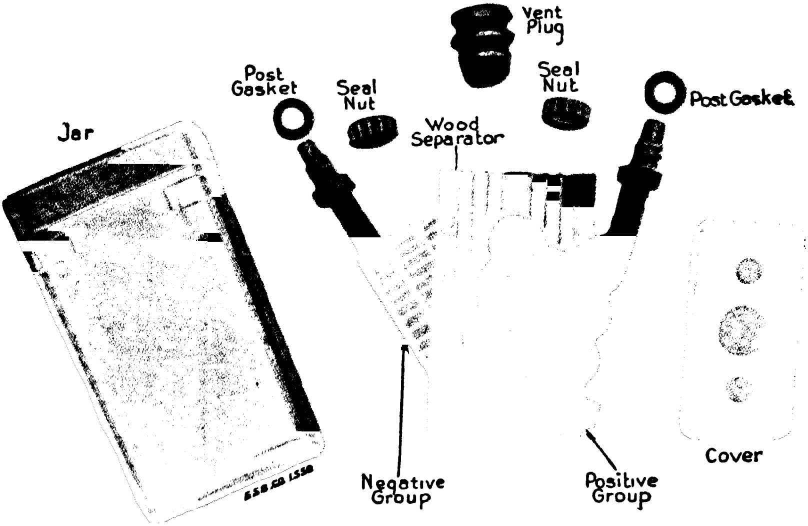
Fig. 1,594.—Appearance of Faure or pasted type grid after active material is pasted.

NOTE.—***The Faure or pasted type plate*** is generally known as a "grid type" and is used exclusively in batteries for vehicles.

NOTE.—***Pasted plates*** of one polarity may be used with Plante plates of opposite polarity. Plates of different design and age, however, should not be used together in any positive or negative group of a cell, on account of local action which will take place between the plates.

electrodes. These plates are immersed in a solution of copper sulphate. Cells belonging to this class are not employed in commercial practice, being useful only for laboratory experiments.

Lead zinc cells are similar to the preceding type, but differ by having zinc for the negative electrode, and zinc sulphate for the electrolyte. The voltage of these cells is slightly higher than that of the ordinary cell, and their capacity per unit of total weight is high, but they are apt to lose their charge on open circuit, besides they possess most of the disadvantages of the Plante cells.



Figs. 1,595 to 1,602.—Parts of Exide cell for railway service with positive group of Manchester type plates.

Alkaline zincate cells have copper for the positive, and iron for the negative electrode. The electrolyte is composed of sodium, or potassium, zincate. Cells of this type are used to some extent for traction purposes.

In addition to the above, there are some special forms of cell which do not belong to the four preceding types.

Ques. Describe the Plante type.

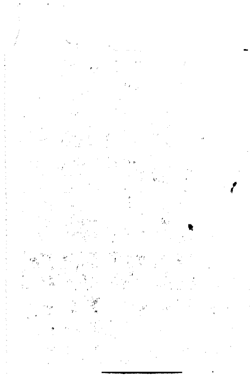
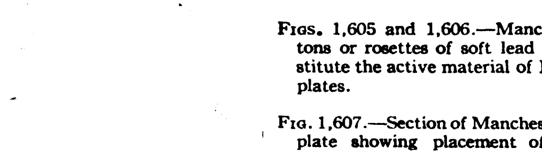


FIG. 1,603.—Exide Manchester type positive plate. ***In construction*** the grid is a cast lead antimony alloy. This alloy unlike pure lead resists the "forming" action during charge and discharge. The grid is provided with circular openings, slightly tapering toward the center, into which are forced by hydraulic pressure, the rosettes or buttons of soft lead which constitute the active portion of the plate. These buttons are formed of strips of pure lead, corrugated transversely and rolled into a spiral. After being forced into place in the grid they are subjected to the "forming" process, whereby the active material or lead-peroxide is developed electro-chemically on the transverse surfaces. The expansive action of this forming process, combining with the "hour glass" shape of the openings, securely locks the buttons in place.

FIG. 1,604.—Exide box negative plate. ***In construction,*** the grid which is of lead antimony alloy is formed of horizontal and vertical ribs, spaced about 1 in. apart, forming pockets closed on both sides with perforated sheet lead, in which pockets the active material is permanently held in place. Thus, the grid and the active material are not necessarily of the same composition, as is the case with other types of negative plate, but each is of the composition best designed for the functions to be performed.

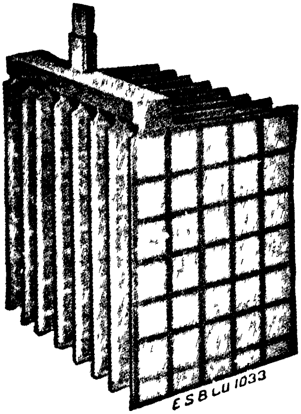


FIGS. 1,605 and 1,606.—Manchester buttons or rosettes of soft lead which constitute the active material of Manchester plates.

FIG. 1,607.—Section of Manchester positive plate showing placement of soft lead buttons.

Ans. In the Plante type the lead is chemically attacked and finally converted into lead peroxide, probably after it has gone through several intermediate changes. The plates are all formed as positive plates first and then all that are intended for negative plates are reversed, the peroxide being changed into sponge lead.

Ques. What is done to make the Plante plate more efficient?



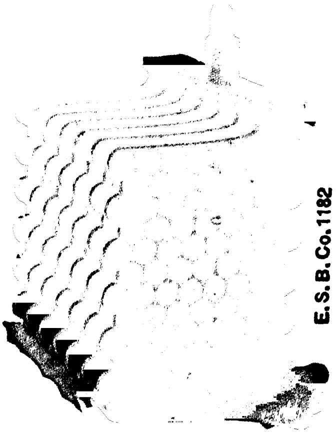


Fig. 1,608.—Exide box negative group.
Fig. 1,609.—Exide Manchester positive group.

Ans. The surfaces are finely subdivided, the following methods being those commonly used: scoring, grooving, casting, laminating, pressing, and by the use of lead wool.

Ques. Describe the Faure or pasted type.

Ans. This form of plate is constructed by attaching the active material by some mechanical means to a grid proper.

The active material first used for this purpose was red lead, which was reduced in a short time to lead peroxide when connected as the positive or anode, or to spongy metallic lead when connected as the cathode or negative, thus forming plates of the same chemical compound as in the Plante type.

The materials used at the present time by the manufacturers for making this paste are largely a secret with them, but in general they consist of pulverized lead or lead oxide mixed with some liquid to make a paste.

Ques. How do Faure plates compare with those of the Plante type?

Ans. They are usually lighter and have a higher capacity, but have a tendency to shed the material from the grid, thus making the battery useless.

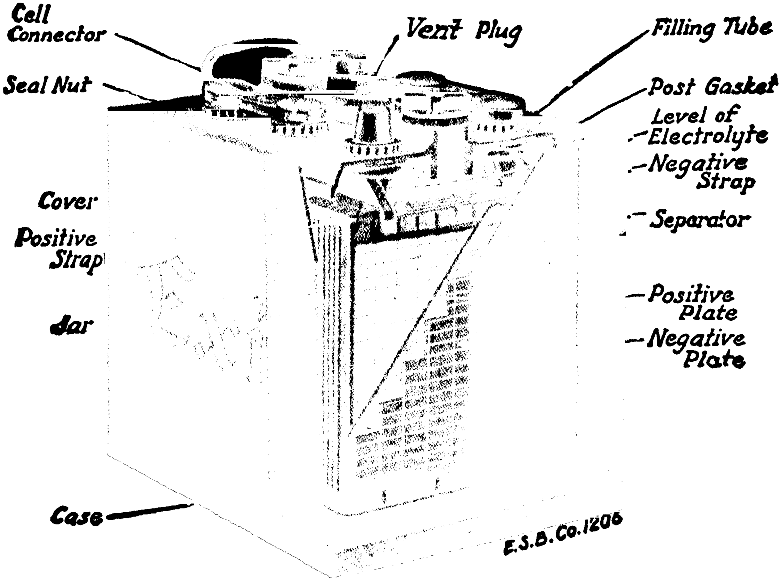
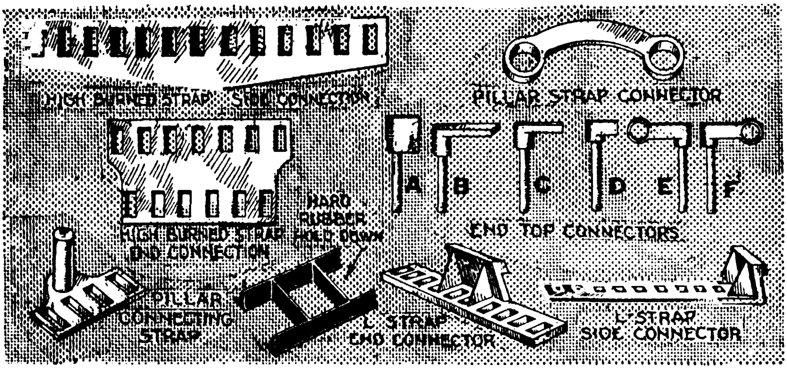


FIG. 1,610.—Sectional view of Exide battery showing construction.

Many ways have been tried for mechanically holding the active material on the grid, the general method involving a special design in the shape of the grid. Some of these designs are: 1, solid perforated sheets of lattice work; 2, corrugated and solid recess plates not perforated; 3, ribbed plates with projecting portions; 4, grid cast around active material; 5, lead envelopes, and 6, triangular troughs as horizontal ribs.

The Electrolyte.—Sulphuric acid is generally used as electrolyte; the acid should be made from sulphur and not from pyrites, as the latter is liable to contain injurious substances.



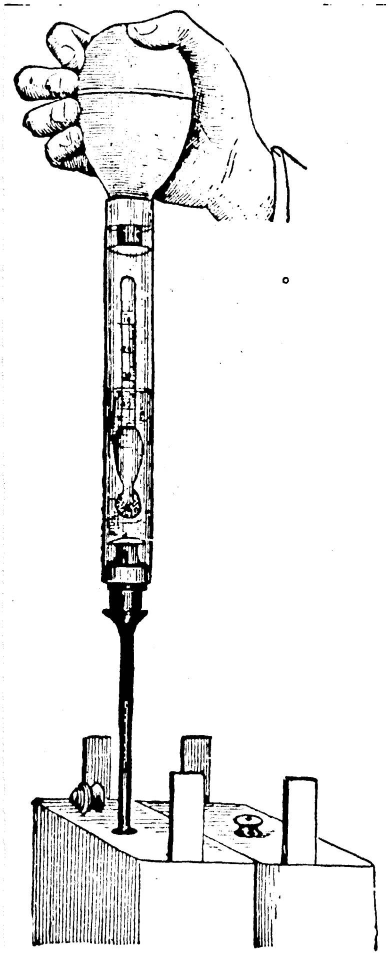
FIGS. 1,611 to 1,623.—Typical connecting straps and connectors.

Ques. How is the electrolyte prepared?

Ans. One part of chemically pure concentrated sulphuric acid is mixed with several parts of water. The proportion of water differs with several types of cell from three to eight parts, as specified in the directions accompanying the cells.

Ques. What test is necessary in preparing the electrolyte?

Ans. In mixing the water and acid, the hydrometer should be used to test the specific gravity of both the acid and the



solution. The most suitable acid should show a specific gravity of about 1.760 or 66° Baumé.

Ques. In preparing the electrolyte, how should the water and acid be mixed?

Ans. The mixture should be be made by pouring the acid slowly into the water, *never the reverse.* As cannot be too strongly stated, in mixing, the liquid should be stirred with

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NOTE —*Specific gravity* is the weight of a given substance relative to an equal *bulk* of some other substance which is taken as a standard of comparison Water is the standard for liquids In the laboratory the *specific gravity bottle* is often used in determining the specific gravity of a liquid The capacity of the bottle is 1,000 grains of pure water When it is filled with spirits of wine and weighed in a balance (together with a counterpoise for the weight of the bottle, which of course is constant), it will weigh considerably less than 1,000 grains, in fact, the bottle will contain only about 917 grains of proof spirit, therefore, taking the specific gravity of water as unity, 1 or 1 000, the specific gravity of spirits of wine is 0 917. If, on the other hand, the bottle be filled with sulphuric acid, it will weigh about 1,850 grains; hence, the specific gravity of sulphuric acid is said to be 1 850 *A more convenient method* is by the use of the hydrometer syringe.

FIG. 1,624 —The hydrometer syringe, a convenient device for testing storage battery cells. By slightly compressing the bulb and inserting the slender tube through the vent hole in the cover of the cell sufficient acid may be drawn up to float the hydrometer within the large glass tube, and the reading can be made at once The acid is returned to the cell by again compressing the bulb, and the reading of the next cell taken. The laborious and uncleanly method of drawing out sufficient acid by a syringe is thus avoided.

a clean wooden stick, the acid being added to the water slowly; the acid is corrosive and will painfully burn the flesh.

Distilled or rain water should be used in preparing the electrolyte. When made, the solution should be allowed to cool for several hours or until its temperature is approximately that of the atmosphere (60 being the average). At this point it should have a specific gravity of about 1.200 or 25° Baumé. If the hydrometer show a higher reading, water may be added until the correct reading is obtained; if a lower reading, dilute acid may be added with similar intent.

SPECIFIC GRAVITY TABLE

Sulphuric acid (Per cent.).	Water (Per cent.).	Specific gravity of Mixture.
50	50	1.398
47	53	1.370
44	56	1.342
41	59	1.315
38	62	1.289
35	65	1.264
32	68	1.239
29	71	1.215
26	74	1.190
23	77	1.167
20	80	1.144
17	83	1.121
14	86	1.098
10	90	1.068

The electrolyte should never be mixed in jars containing the battery plates, but preferably in stone vessels, specially prepared for the purpose. Furthermore, it should never be placed in the cell until perfectly cool.

Ques. What is the effect of mixing the acid and the water?

Ans. The mixture becomes hot.

Before using, the mixture should be allowed to cool.

Ques. What kind of a vessel should be used?

Ans. The vessel should be of glass, glazed earthenware, or lead.

Ques. At what density is the resistance of dilute sulphuric acid at a minimum?

Ans. At 1.260.

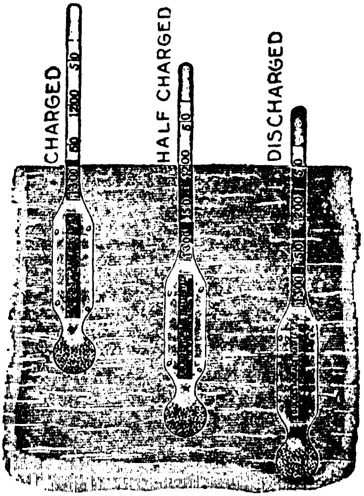

Fig. 1,625.—View of hydrometer and electrolyte showing state of charge of cell as indicated by the density of the solution.

The percentage of concentrated sulphuric acid and of water per 100 parts of the electrolyte for various specific gravities is given on the page following.

The electrolyte of the desired specific gravity may be purchased ready for use, but in cases where it is desirable to save freight, the acid may be diluted at the point of installation.

Ques. What is the effect of a deep containing vessel?

Ans. Parts of the plate surface may do more than their share of the work due to the difference in the density of the electrolyte at the top and bottom. The containing vessel should, therefore, never be deeper than about 20 inches unless some artificial means of acid circulation be used.

Ques. What is the effect of changes in temperature on the electrolyte?

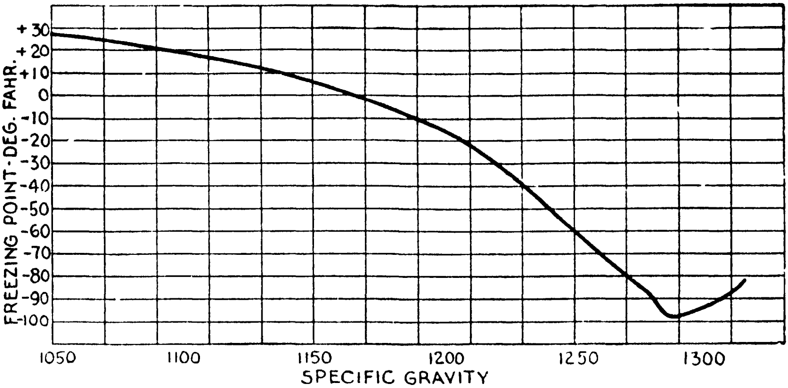

FIG. 1,626.—Freezing points of electrolyte. ***The freezing point*** of a battery depends upon its strength. For instance, a solution with a strength or specific gravity of 1.250 will not freeze until cooled to a temperature of 62° below zero Fahr. A strength of 1.150 will freeze at 5° above zero, hence there is little danger of freezing except when the battery is completely discharged. Moreover, at these freezing points, the solution is slushy and does not become hard until the temperature goes still lower. ***If water be added*** to a battery in freezing weather and then not stirred in with the solution by charging the battery, it will remain on top of the solution and may freeze.

Ans. The resistance of the electrolyte is changed, being less for increase of temperature.

Ques. How should the cells be filled?

Ans. Enough of the electrolyte should be poured into the jars to completely cover the plates, or to within about a half inch of the top edge of the jar. Large cells should be filled by means of an acid proof pump and rubber hose.

Ques. What change takes place after filling the jars?

Ans. The specific gravity of the electrolyte will fall considerably, but will rise again when the battery is charged.

Ques. What may be said with respect to the density of the electrolyte?

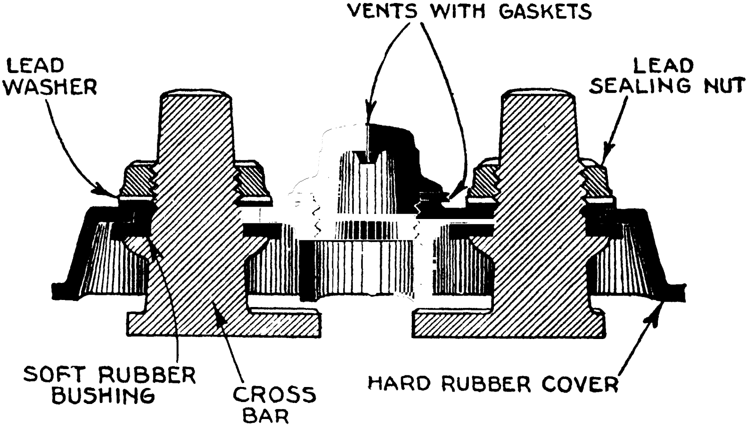

FIG. 1,627.—Top of Gould cell showing construction.

Ans. It should never exceed 1.300 (usually from 1.280 to 1.295) when the battery is fully charged.

Ques. How much electrolyte is used per 100 ampere hours battery capacity, on an 8 hour rating?

Ans. About ten pounds; in automobile batteries, about four pounds is sufficient.

Ques. What should be done with old electrolyte?

Ans. When a battery is taken down the electrolyte may be saved and used when re-assembling the battery, providing great care be exercised when pouring it out of the jar, so as not to draw off with it any of the sediment.

It should be stored in convenient receptacles, preferably carboys, which have been thoroughly washed and never used for any other purpose.

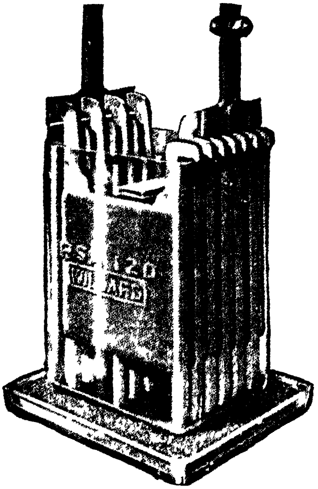

Fig. 1,628.—Willard A R A. signal, lead Plante plate cell in glass jar.

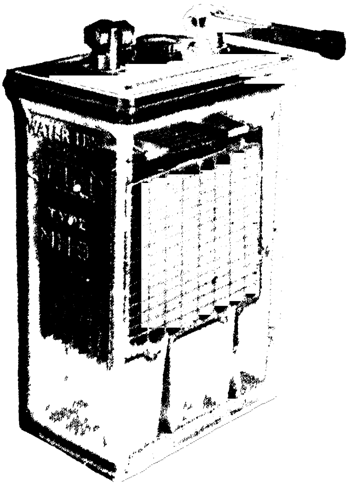

Fig. 1,629.—Willard signal, Faure plate cell in sealed glass jar.

The electrolyte saved in this manner will not, however, be sufficient to refill the battery, and as some new electrolyte will be required, in general it is recommended that the old supply be thrown away and all new electrolyte (1.200 specific gravity) be used when re-assembling.

Voltage of a Secondary Cell.—This depends on the density of the electrolyte, the character of the electrodes and condition of the cell; it is independent of the size of the cell.

The voltage of a lead sulphuric acid cell when being charged is from 2 to 2.5 volts. While the cell is being discharged, it decreases from 2 to 1.7 volts. The voltage due to the density of the electrolyte may be calculated from the following formula:

$$V = 1.85 + .917\ (S - s)$$

in which

V = voltage;
S = specific gravity of the electrolyte;
s = specific gravity of water at the temperature of observation.

TEST QUESTIONS

1. *Give the theory of the storage battery.*
2. *Describe the storage cell.*
3. *Describe the electrolyte generally used.*
4. *What is the effect of the current passing through the electrolyte?*
5. *What is the prime condition for operation of a storage battery?*
6. *What happens when the charging current is discontinued, and the two electrodes joined by an outside wire?*
7. *What are the three general classes of storage cells?*
8. *Describe the Plante type.*
9. *What is done to make the Plante plate more efficient?*
10. *Describe the Faure or pasted type.*

11. *How do Faure plates compare with those of the Planté type?*
12. *What test is necessary in preparing the electrolyte?*
13. *In preparing the electrolyte, how should the water and acid be mixed?*
14. *What is the effect of mixing the acid and the water?*
15. *What kind of a vessel should be used?*
16. *What is the effect of changes in temperature on the electrolyte?*
17. *How should the cells be filled?*
18. *What may be said with respect to the density of the electrolyte?*
19. *What should be done with old electrolyte?*
20. *Upon what does the voltage of a storage cell depend?*

CHAPTER 41

Storage Battery Systems

Storage batteries are used for many purposes, such as to supply current for electric vehicles, gas engine ignition, lighting, and in connection with power stations and distribution work.

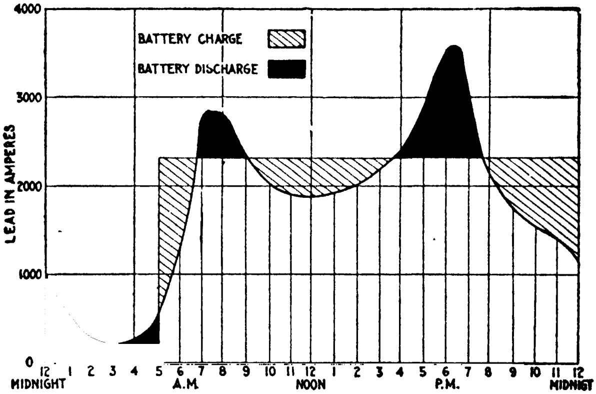

Fig. 1,630.—Load curve showing use of storage battery as an aid to the generating machinery. In the diagram, it is seen that the battery discharges at minimum and maximum loads and is charged at other times, the battery furnishing current for the entire minimum load and part of the maximum load.

The latter is an important field, the storage battery being used in connection with the power station for the following purposes:

1. To carry the peak load, during hours of maximum demand;
2. To carry the entire load during hours of minimum demand, or for a short time in case of emergency;
3. To act as an equalizer;

4. For regulation of load and voltage;
5. As compensation for feeder drop;
6. As a preventive against shut downs.

In almost every electric lighting plant there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery. In such cases, storage batteries may usually be used to advantage to aid in carrying the maximum load and to supply the entire current at minimum load as illustrated in fig. 1,630. In other words, batteries are substituted for a certain portion of the machinery plant or are used in place of the latter.

Ques. What provision must be made in power plants when storage batteries are not used?

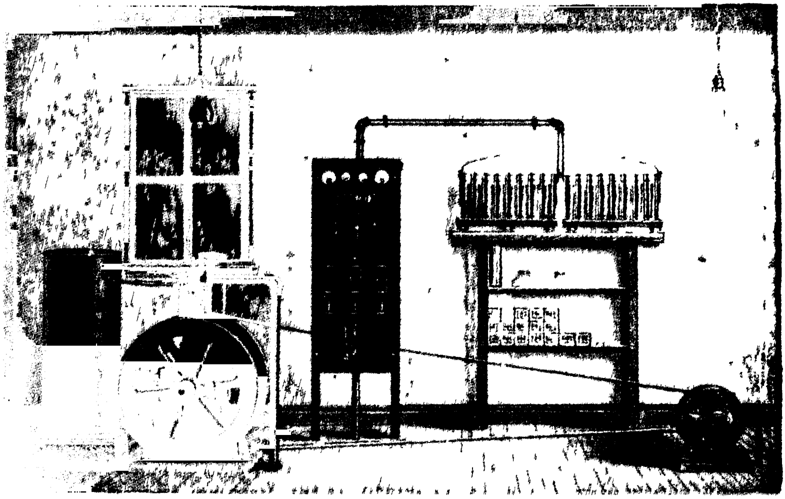

FIG. 1,631.—Fairbanks-Morse lighting outfit. The above cut illustrates a 2 horse power vertical special gasoline or kerosene oil engine belted to a 9 kw. compound wound 32 volt dynamo. It will supply a maximum of 42-20 watt, or 50-15 watt 32 volt Tungsten lamps and is built and balanced, so that current can be taken direct from the dynamo without flicker in the lights. The storage battery has 16 cells and a capacity of 4½ amperes for 7½ hours at 32 volts. This will supply seven 20 watt Tungsten lamps for 7½ hours, or nine 15 watt lamps for 7½ hours. The switchboard is arranged so as to give 24 hours service. It is customary to run the engine during most of the lighting period and to use the battery for lights late at night. If the whole number of lights be not used when the engine and dynamo are in operation, the surplus is used to charge the battery.

Ans. The capacity of the generating machinery must be sufficient for the heaviest overloads which may occur, and it must be operated continuously for 24 hours a day in the majority of central stations supplying current for lighting and power.

Ques. What results are obtained with this method of working?

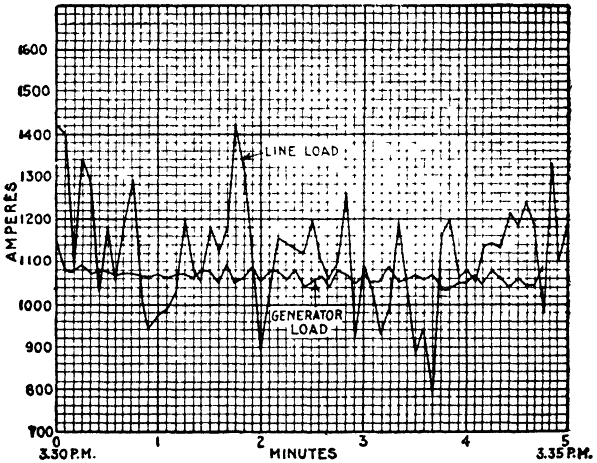

Fig. 1,632.—Diagram showing effect of storage battery in regulating the dynamo load in a combined railway and lighting plant. In this case the average and line loads are about equal and the battery covers the instantaneous fluctuations. It will be noted that while the line load fluctuations vary between 780 and 1,420 amperes, those of the dynamo load are kept at an average between 1,030 and 1,160 amperes.

Ans. The engines working under very variable loads, not only operate at low efficiency, but are continually subjected to severe mechanical strains.

Ques. How may greater efficiency be secured with steam engines under variable loads?

Ans. Judicious selection of the number and sizes of the engines enables them to be worked in most cases at a considerable fraction of their full capacity nearly all the time.

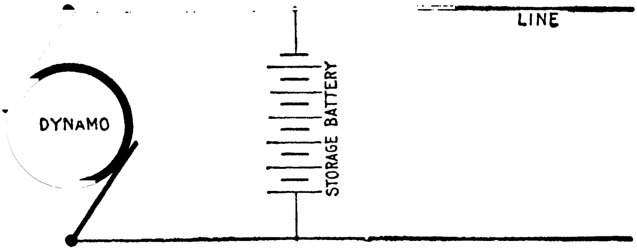

FIG. 1,633.—Storage battery connected in parallel with a dynamo. ***This arrangement*** enables the dynamo to be stopped for a considerable portion of the time, and thus saves labor and attention. It also acts to prevent fluctuations as in a dynamo driven by a gas engine whose speed varies periodically because of the nature of its cycle of operation. The circuit includes a reverse current circuit breaker or discriminating cut out (not shown) to prevent battery discharging through dynamos when the latter is not running.

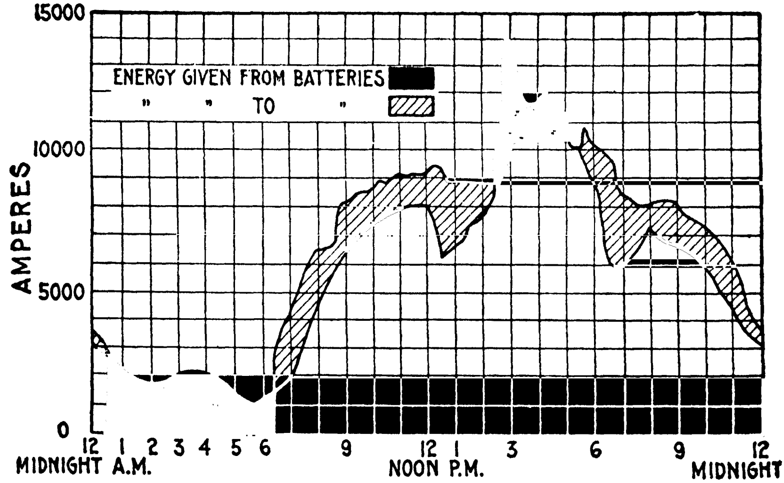

FIG. 1,634.—Diagram showing action of storage battery as a reservoir of reserve power. The figure shows an actual load curve from an Edison station for 24 hours. A sudden storm caused the load to be thrown on very quickly, the peak of the load being higher than usual.

Ques. What further improvement is secured in most cases with the storage battery?

Ans. The plant is made more flexible, and the economy of the engines is increased by making their loads nearer uniform, and nearer to full capacity while they are running.

Ques. What is the effect of a battery connected in parallel with a dynamo, as in fig. 1,633?

Ans. It is not necessary for the dynamo to have a capacity exceeding that which is sufficient for the average daily load, at which it may be worked practically all the time.

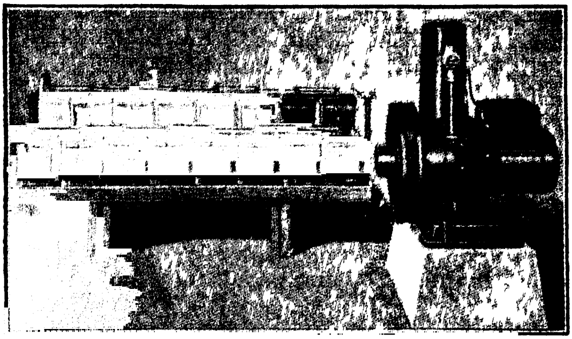

FIG 1,635—Westinghouse farm light and power plant.

When the load is below the average, the dynamo charges the battery, and when the load rises above the average, during the hours of maximum demand, the battery discharges into the line in parallel with the dynamo. During the hours of minimum demand the engines may be shut down and the necessary current supplied from the battery alone, thus not only increasing the efficiency of the plant, but serving to maintain a steadier pressure under fluctuating loads.

Ques. What is understood by the expression "floating the battery on the line"?

Ans. A storage battery is said to *float* on a line when connected across the circuit at some distance from the power station, so that a heavy load on the line, within the range of the battery influence, causes sufficient line drop to allow the battery to discharge, while with a light load on the line, the drop is small and the impressed voltage at the battery high enough to charge the battery. This usage is confined chiefly to electric railway service, where large voltage changes are permissible.

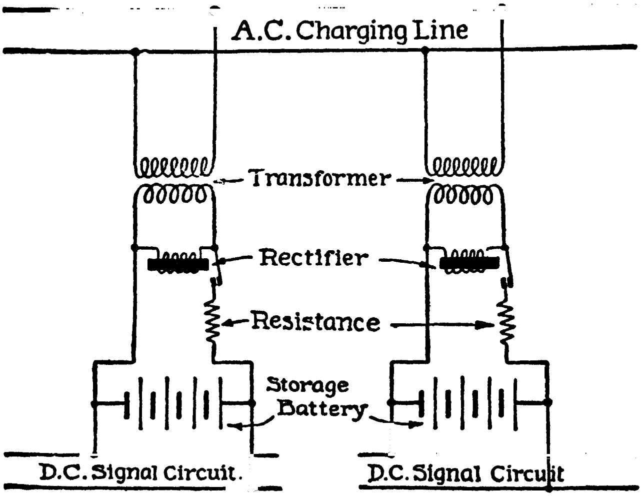

FIG. 1,636 —Exide floating battery system for railway signaling, connected to *a c.* charging line. ***This system provides*** an independent reservoir of electrical energy at each signal, always charged and connected to the signal circuit to supply *d c.* to the latter during any interruption of the normal supply, to insure no interruption of the signal service.

Ques. When the battery is floated on the line, how may the amount of charge be made to approximately equal the amount of discharge?

Ans. By properly proportioning the number of cells in series.

Connections and Circuit Control Apparatus.—When a storage battery is used on an electric lighting plant, provision must be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel, and

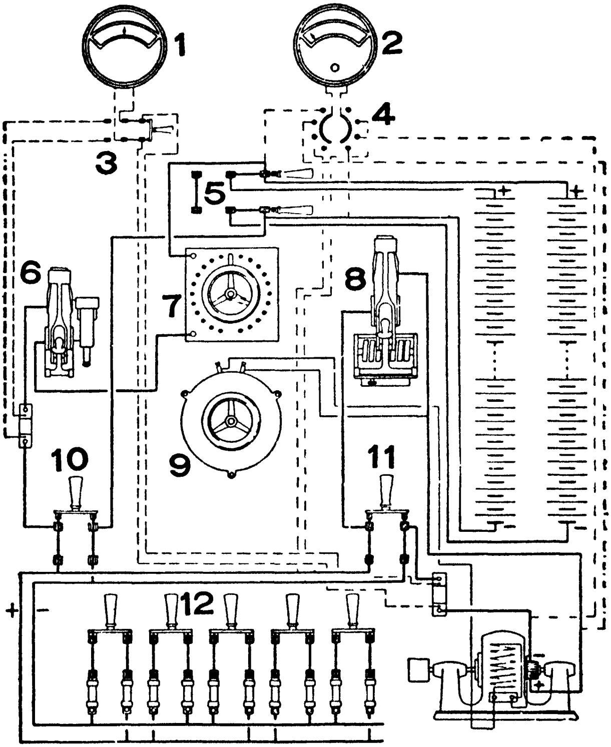

FIG. 1,637.—Parallel charge, series discharge including dynamo and distribution circuits. 1, ammeter; 2, volt meter; 3, ammeter switch; 4, volt meter switch; 5, series parallel switches; 6, battery circuit breaker; 7, battery rheostat; 8, overload and reverse current circuit breaker (discriminating cut out); 9, dynamo field rheostat; 10, battery switch; 11, dynamo switch; 12, switches to distribution circuits.

it should be possible to charge the battery at the same time the lamps are being supplied. To accomplish these results requires three switches. for the following connections:

1. To connect the lamps to the dynamo;
2. To connect the lamps to the battery;
3. To connect the battery to the dynamo.

In some plants, the first switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use.

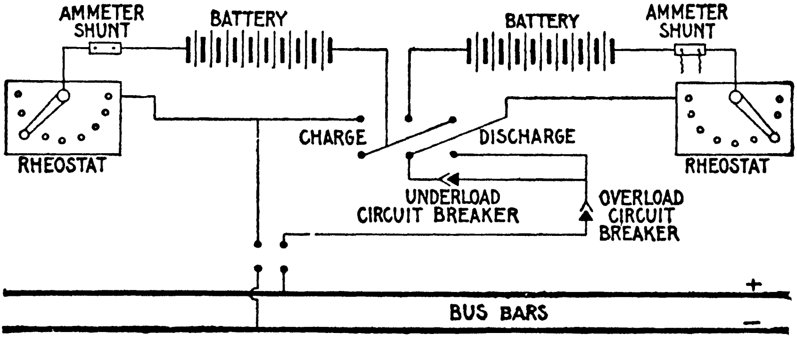

FIG. 1,638.—Diagram of connections arranged for charging battery in two parallel groups and discharging in series, the charge and discharge being controlled by variable resistances In yacht lighting the limited space generally prohibits the use of a charging booster, and in such instances this method of charge and discharge control is the usual practice. In case the dynamo from which the battery is charged has sufficient range in voltage to charge all cells in series, a charging booster is not required, nor is it necessary to connect groups of cells in parallel, as the dynamo voltage may be varied as charge proceeds.

It is desirable, however, to have all three switches in every plant in order to be able to supply lamps and charge the battery at any time.

In the battery circuit there should be an ammeter having a scale on both sides of zero, to show whether the battery is being charged or discharged, as well as the value of the current. Another similar ammeter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third ammeter is desirable in the lamp circuit, to show the total current supplied to the lamps, but it need only indicate on one side of zero, since the current there always flows in the same direction.

A volt meter is required with a three way switch to connect it to the dynamo, battery or lamps, and a circuit breaker must be inserted in the battery circuit in order that it may be opened when the current becomes excessive.

A discriminating cut out or reverse current circuit breaker is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from any cause the voltage of the latter drop below that of the battery. This completes the ordinary measuring and circuit controlling apparatus employed with storage batteries.

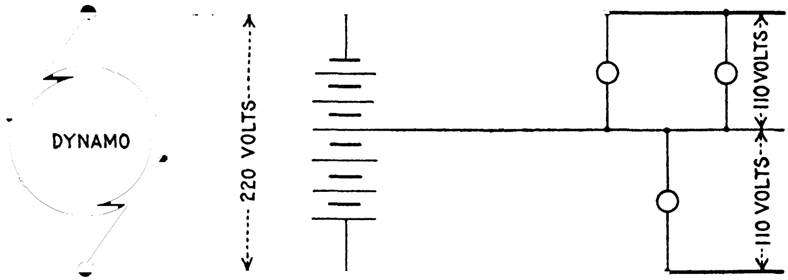

Fig. 1,639.—Diagram showing three wire system with one dynamo and storage battery. A 220 volt dynamo charges a storage battery of corresponding pressure, which in turn subdivides the pressure and supplies a three wire system, the neutral wire of which is connected to the middle point of the battery as shown.

Methods of Control for Storage Batteries.—As the external voltage of a storage battery varies with the amount of charge it contains and with the direction of the current, it is necessary to employ some means for compensating this variation in order to maintain a constant voltage on the line supplied by the battery. The various devices used for this purpose are as follows:

1. Variable resistances;
2. End cell switches;
3. Reverse pressure cells;
4. Boosters.

The particular method selected will depend upon the size of the battery, the purpose for which it is used, the allowable limits of current and voltage variations, the cost of the system, etc.

Variable Resistance.—Regulation by variable resistance may be used advantageously only with batteries of small capacity, and in small lighting plants such as those of yachts, where the space available for battery auxiliaries is limited, and where the cost of energy is so low that the loss of power in the resistance is not objectionable.

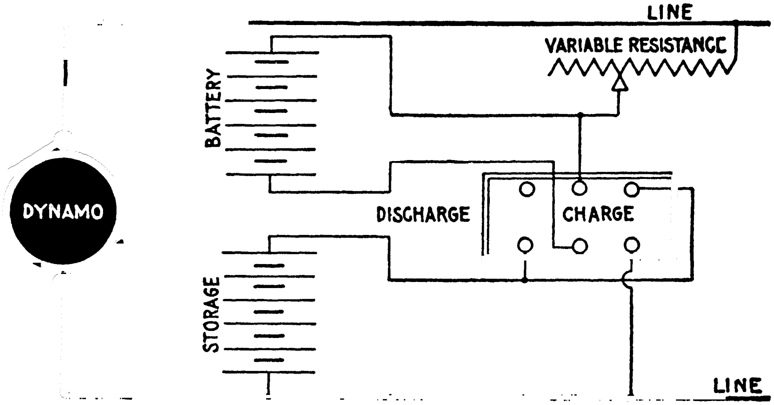

FIG. 1,640.—Variable resistance method of regulation for storage battery; diagram showing connections for charging two halves of a battery in parallel.

The connections for one of the simplest methods is shown in fig. 1,640. The battery is divided into two halves, which are connected in series for discharging and in parallel for charging.

Since the voltage of each cell at the end of a discharge should not be lower than 1.8 volts, a battery intended for use on a 110 volt lighting circuit will require $110 \div 1.8 = 62$ cells. The voltage necessary, however, for each cell at the end of a charge is about 2.6 volts, or a total of $2.6 \times 62 = 161$ volts for the battery, a value which is far above the line voltage.

By dividing the battery into two halves and connecting them in parallel only 80.5 volts are necessary for charging. The excess voltage of the line.

29.5 volts is taken up by the resistance, which also controls the output of the battery on discharge.

End Cell Switches.—These may be used to advantage in small installations where there is not demand for current during the day, or where the charging is done by means of *boosters*.

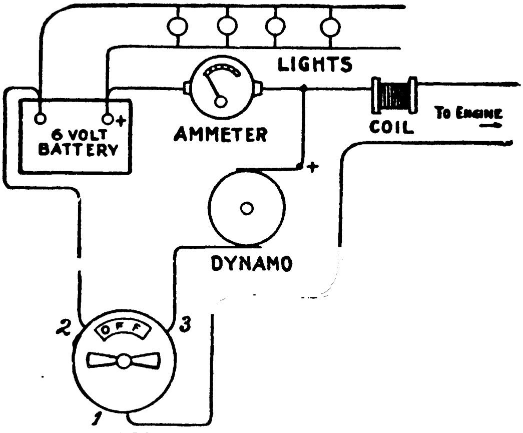

Fig. 1,641.—Diagram showing connections for ignition outfit. The charging switch has four indications—"Off," "Battery," "Dynamo" and "Charge." When engine is at rest switch is turned to "Off." The first turn brings it to "Battery," enabling the engine to be started. Next turn cuts battery off and puts "Dynamo" direct on engine. The next turn brings the switch to "Charge." Dynamo then charges the battery and surplus current is stored up. Next turn is "Off," which stops engine and disconnects battery from dynamo. Test the dynamo wires with test paper (negative makes mark). Put positive of dynamo to positive of battery. Dynamo should be regulated to charge at about four amperes.

Ques. What is an end cell switch?

Ans. A form of switch employed in connection with a storage battery in order to control the end cells for regulating the voltage.

Ques. Describe the construction of an end cell switch.

Ans. This is shown in fig. 1,642.

The switch contact arm is made in two parts, A and B, which are insulated from each other as shown, and connected with each other through the protective resistance R. The end cell contacts are so spaced that when the main current carrying part A, of the switch arm is squarely on one end cell contact such as X, the part B, does not touch any other contact such as Y, but when the switch arm is advanced for cutting into circuit another end cell, the part B, reaches the contact Y, before the part A, leaves the contact X, thus keeping the battery circuit closed, while the resistance R, limits the current in the short circuited cell at the instant the switch arm passes from one end cell contact to the next.

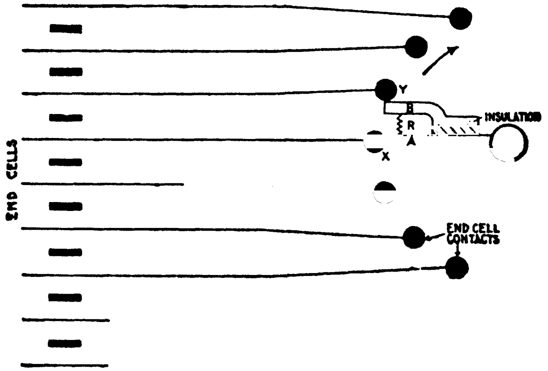

FIG 1,642 —Diagram of end cell switch ***This form of switch*** controls several cells at one end of a storage battery and is used for regulating the voltage The requirement of an end cell switch is that in switching from one end cell contact to another, the discharging circuit must not be opened, neither must the moving arm touch one contact before leaving the one adjacent, since the joining of two contacts will short circuit the cells connected thereto. To accomplish this, the spacings of the two arms and contacts are such that when the main arm A is squarely on an end cell contact, the advance or auxiliary arm B touches no other contact, but in passing from one point to the next, the advance arm reaches the contact toward which it is moving before the main arm leaves its contact The resistance X, between the two points prevents short circuiting, and the current to the main circuit is never broken.

Ques. How should the conductors joining the end cells to the end cell switch contacts be proportioned?

Ans. They must have the same sectional area as the conductors of the main circuit.

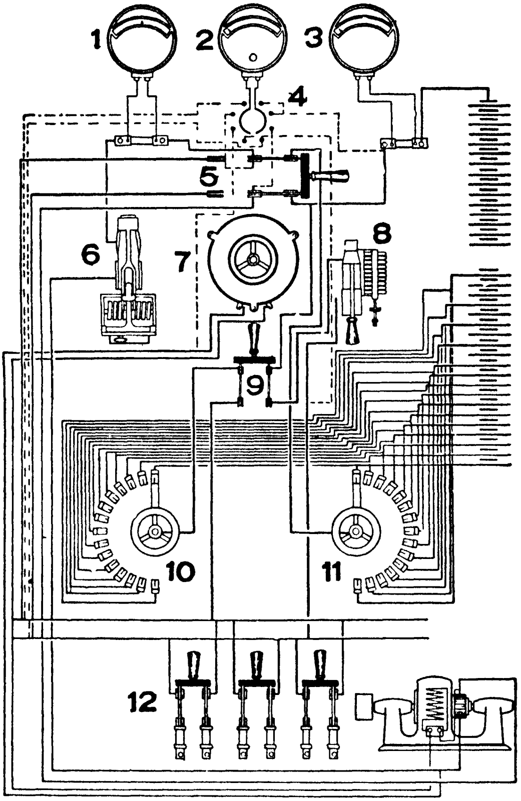

FIG. 1,643 —High voltage charge. ***End cell regulation.*** 1, dynamo ammeter; 2, volt meter; 3, battery ammeter; 4, volt meter switch, 5, dynamo switch, 6, dynamo circuit breaker over load and reverse; 7, dynamo field rheostat; 8, battery circuit breaker; 9, battery switch; 10, discharge end cell switch; 11, charging end cell switch, 12, switches to distributing circuits. The battery is charged in one series directly from the dynamo, which has a pressure range to 155 volts, and the charging current is controlled by the dynamo field rehostat. Two end cell switches are required so that the lighting circuits may be supplied while the battery is charging, the power voltage for the lamps being obtained by adjusting the position of the end cell switch connected to the lighting circuit. This is an overload breaker in the battery circuits and an overload breaker with reverse current trip in the dynamo circuit, the latter protecting the dynamos against overload and reversal of current.

The reason for this is that when any end cell is in use, the conductor connecting it to the switch becomes a part of the main circuit. An allowance of 1,000 amperes per sq. in., when the battery is discharging at the two-hour rate, is considered good practice.

Ques. Describe some of the features of end cell switch construction.

Ans. Those of small capacity are made circular; the larger sizes are made horizontal in form, and both types may be either operated by hand or motor driven.

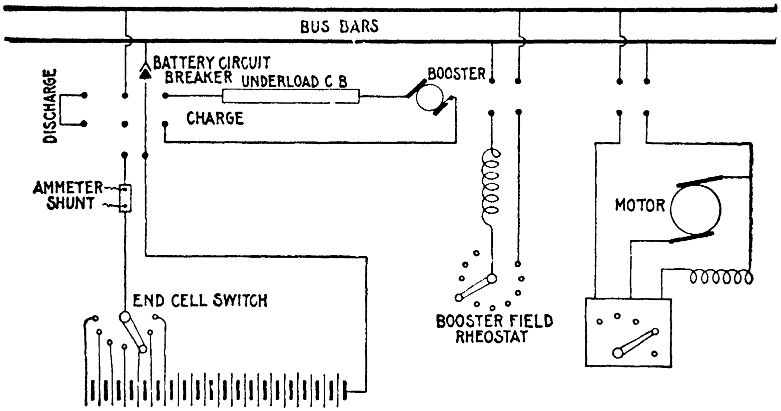

FIG. 1,641 —Diagram of connections of a battery equipment for a residential lighting plant. In the diagram the volt meter and volt meter connections have been omitted The bus bars on the battery panel are connected directly to the bus bars on the dynamo panel In this installation the dynamos are run during the afternoon on discharge, being regulated by means of an end cell switch On charge the pressure above that of the bus bars, required to bring all cells up to full charge, is supplied by means of a motor driven charging booster, the voltage at the armature being suitably varied by changing the field excitation.

Ques. Where are end cell switches of large capacity located?

Ans. Generally they are placed as near the battery room as possible to avoid the cost of running the heavy conductors, and when such switches are motor driven, the usual practice is to control their operation from the main switchboard.

In fig. 1,645 is shown the method of regulation with an end switch. The diagram shows the battery being charged with the main switch open, and the voltage of the dynamo raised to the charging pressure. During discharge the cells are connected in series, and as the voltage of each cell at the beginning of discharge is at least 2.1 volts, only 52 or 53 cells are required to give the desired pressure of 110 volts, but as the discharge continues, and the voltage of each cell decreases, the end cells, 1,2,3,4, etc., are cut into circuit successively by means of the end cell switch, thereby adding to and compensating the drop in the total voltage until, at the end of discharge when the voltage of each cell has fallen to 1.8 volts, the entire 62 cells are in series to supply the required line pressure.

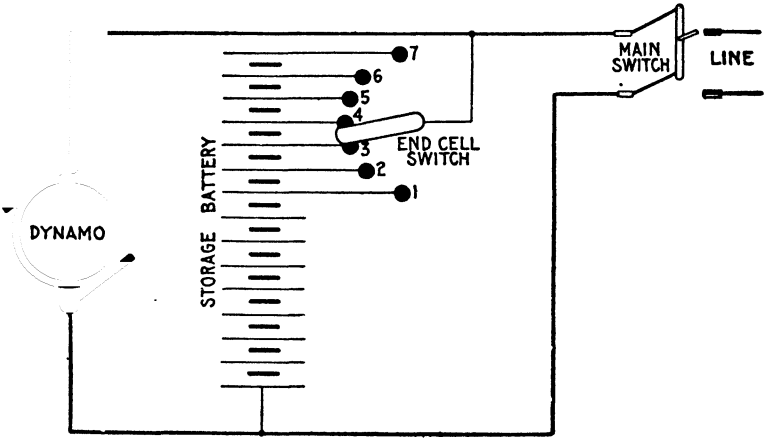

Fig. 1,645.—End cells witch control for storage battery; connections showing main line open when the battery is being charged.

For a 110 volt circuit, the number of cells required is $110 \div 1.8 = 61$, and the number in series when the battery begins to discharge is $110 \div 2.1 = 52$. Hence, in a 110 volt circuit an arrangement must be provided whereby $61 - 52 = 9$ cells may be cut out or switched in, one by one.

The number of end cells for any voltage may be obtained by the following formula:

$$\text{Number of end cells} = \frac{E}{1.8} - \frac{E}{2.1}$$

E = voltage of supply circuit;
1.8 = minimum voltage of cell during discharge;
2.1 = voltage of fully charged cell.

Reverse Pressure Cells.—These consist of *unformed lead plates immersed in the ordinary electrolyte of dilute sulphuric acid.*

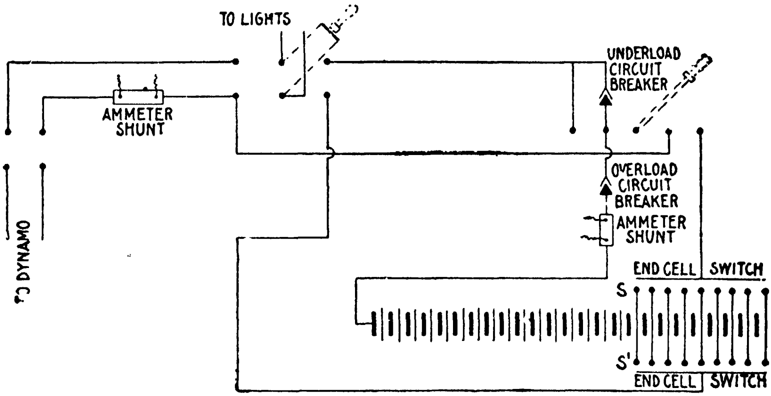

FIG. 1,646.—Diagram showing method of charging a storage battery at one voltage and supplying lights at a different voltage. As may be seen, two end cell switches are required. The voltage of the supply current is adjusted by the number of cells in series on switch S', while switch S, is moved to cut out cells as they become fully charged. In this instance the end cells included between the contact arms of the two end cell switches must be of sufficient size to receive the charging current, plus the current to the supply circuit. If the battery can be charged at times when the dynamo is supplying no other load, only one end cell switch is required.

As they have no active material, they possess no capacity, but are capable of setting up an opposing pressure of about 2 volts each to the discharging current flowing through them, thereby cutting down the total voltage of the battery, so that the net voltage across the line depends on the number of reverse current cells in series in the battery circuit. As the voltage of the battery falls during discharge, the reverse pressure cells are cut out, successively, thus keeping the external or line voltage constant.

It is obvious, that as these cells do not possess any capacity, the number of active cells required in the battery will be the same as when end cell control is employed. Therefore, the reverse pressure cells represent an increase in equipment, which entails an additional expense of at least 8 per cent. For this reason, and also on account of the fact that the amount of energy lost in discharging against reverse pressure cells, is the same as when the resistance methods of controlling the discharge are employed, the use of cells for this purpose is now practically obsolete.

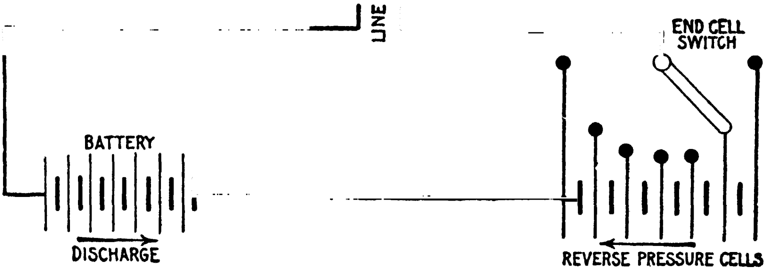

FIG 1,647 —Regulation with reverse pressure cells. *These cells* are merely lead plates placed in an electrolyte of dilute sulphuric acid They have no capacity but set up an opposing or reverse voltage of approximately 2 volts per cell if current be passed through them In using these cells for controlling discharge, the total number of active cells in the battery will be the same as if the method of end cell control had been used Reverse pressure cells represent an increase in equipment of about 8 per cent or more These cells, as shown, are connected in the circuit in opposition to the main battery, and conductors are run from each of them to points on a switch similar to an end cell switch At the beginning of discharge, all the reverse cells are r circuit, acting in opposition to the main battery. As discharge proceeds and the battery voltage falls, the reverse cells are gradually cut out of circuit The only advantage in this method of regulation is that the discharge throughout the battery is uniform, but this fact alone does not warrant such means of regulation on account of the additional expense involved, and the energy loss when discharging against reverse cells is the same as if resistance had been placed in the circuit.

Boosters.—In general, a booster may be defined as *a dynamo inserted in series in a circuit, to change its voltage.* It may be

driven by an electric motor, in which case it is sometimes called a *motor-booster*. The function of a booster is to add to an electric pressure derived from another source.

For instance, if a storage battery be used in conjunction with one or more dynamos to supply current to an electric light installation, the battery cannot be charged from the machines which are feeding the lamps, because it requires a pressure higher than that required for the lamps to

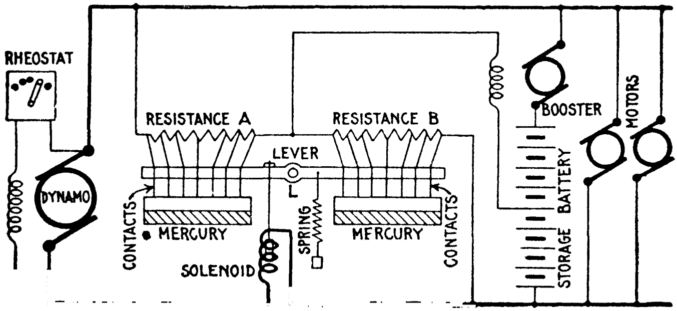

Fig. 1,648.—Diagram of Joseph Bijur's storage battery system (General Storage Battery Co.). The booster field winding has one terminal connected to the middle point of the battery and the other terminal, to the wire joining the resistances A and B. A lever, pivoted at L, carries at either end a number of contact points which dip into troughs of mercury when one end of the lever moves upward or downward. These points are connected to corresponding points on their respective resistances, and therefore all of the resistances connected to contact points which are immersed in the mercury are short circuited. The points are of various lengths, so that when the lever operates, they contact progressively with the mercury. If more of the A, points than the B, points be immersed in the mercury, the resistance of B, is less than that of A, more sections of it being short circuited. Current will therefore flow from the middle point of the battery, through the booster field, and through B, to the negative side of the system, exciting the booster field and producing a booster voltage to charge the battery. Again, if more of the A, points be immersed, the A, resistance becomes the smaller, and current then flows from the positive side of the system through resistance A, through the booster field to the middle point of the battery, the field excitation and the booster pressure produced being in a direction opposite to the first described, and tending to discharge the battery. When the resistances A and B, are equal, there is no pressure to send current in either direction through the booster field coil. When the load on the external circuit is normal, the lever is in a horizontal position, A and B. being equal, no current flows through the booster field hence, no current passes into or out of the battery. With increase of external load, the pull of the solenoid is strengthened by a small increase in dynamo current passing through the winding. This draws down the left end of the lever producing a current in the booster field such as to discharge the battery and assist the dynamo to supply the load demand. A decrease in external load is attended by a slight diminution in dynamo current, the solenoid is weakened and the pull of the spring predominates. This results in a downward movement of the right side of the lever causing excitation of the booster field to produce a pressure to send charge into the battery.

complete the charge. A small dynamo is therefore connected in series with the main machines and the battery, acting in conjunction with the former to provide the necessary pressure.

The power for running such a dynamo is obtained in various ways.

The dynamo or charging booster may be belt driven or arranged on an extension of the armature shaft of the main dynamo; again, it may consist of a single armature with a double winding (fig. 1,649), or a motor and dynamo coupled together on one bed plate. Boosters may be divided into several classes as follows:

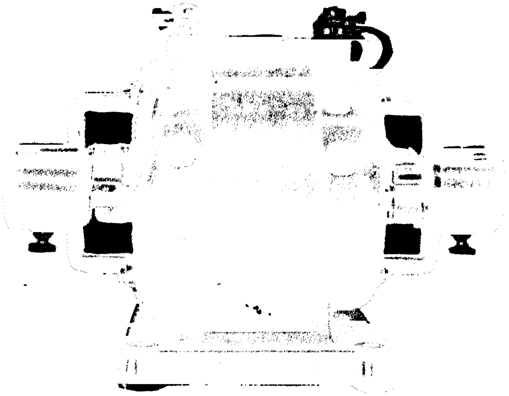

FIG. 1,649.—Typical form of dynamotor. A dynamotor is a combination of dynamo and motor on the same shaft, one receiving current, usually of different voltage, the motor being employed to drive the dynamo with a pressure either higher or lower than that received at the motor terminals. A machine of the dynamotor form, with its windings exactly alike, is often used in three wire systems to balance or equalize the two halves of the circuit.

1. Series boosters;
2. Shunt boosters;
3. Compound boosters;
4. Differential boosters;
5. Constant current boosters;
6. Separately excited boosters.

Series Boosters.—The series booster acts so as to compound the battery, and tends to maintain a constant voltage on the line, whatever the load may be.

Its operation depends on the fact that the dynamo voltage must rise and fall with the load. It can, therefore, be used only with a shunt dynamo or its equivalent as the source of supply.

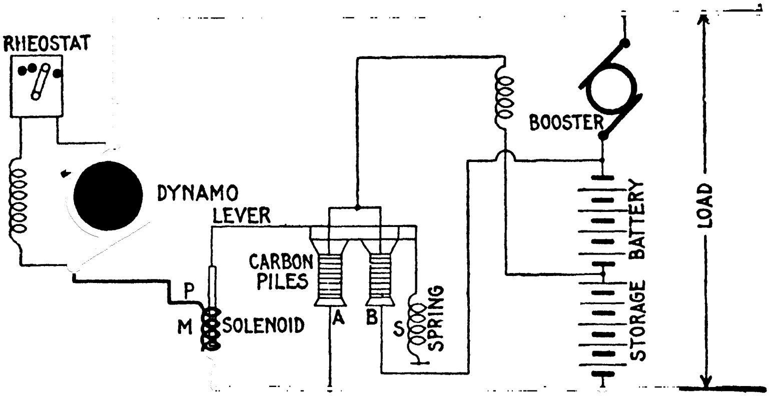

FIG. 1,650—Entz' carbon pile booster system (Electric Storage Battery Co) The booster field winding is connected at one end to the middle point of the battery The other end is connected to the upper contact points of two carbon pile resistances A and B The lower end of A, is connected to the negative side of the battery, and the corresponding end of B to the positive side This arrangement constitutes in effect a potentiometer If the resistance of A, be equal to that of B, there is no pressure in the booster field to establish current through it The drop through A + B is equal to the total battery voltage, and if A = B, the drop from either side of the battery through A or B, is one half the total drop, hence the end of the booster field winding, connected to the upper ends of A and B, is also at the pressure of the middle point of the battery which is likewise the pressure of the other side of the booster field coil Accordingly when A = B there can be no current through the coil When the two resistances are unequal, there will be current through the booster field, its direction depending on which of the resistances is the less, and its magnitude will be proportional to the difference between the two resistances Variations in the pressure on a carbon pile causes variations in its resistance and the solenoid, M, opposed by spring S, both pulling on lever L, which rests on the two piles A and B, controls the relative resistances of the two piles to cause charge and discharge of the battery The solenoid winding is in series with the dynamo circuit and when the load is normal the spring pull is just equal to the magnet pull, and the resistances of A and B, are equal When external load varies, a small but proportional variation in the pull of P, charges the relative resistances of the piles and the booster field is energized to produce a voltage to cause battery charge or discharge

Ques. What use is made of the series booster system?

Ans. It is suited to power, but not to incandescent lighting purposes, being similar in operation to a floating battery. It is not extensively used as the other types give better service, under the same conditions.

Ques. Describe some characteristics of the series booster.

Ans. It is automatic and adjusts its voltage to produce the proper ratio of charge or discharge with varying external load, and it also tends to maintain a constant voltage across the line, under all conditions of change in circuit.

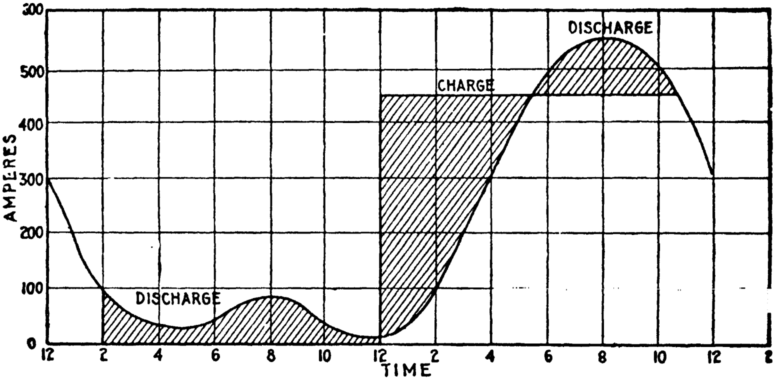

FIG. 1,651.—Load diagram, showing kind of service to which the shunt booster is adapted.

Shunt Boosters.—This type of machine is simply a shunt dynamo, having its armature circuit in series with the line from the main dynamo to the battery.

A rheostat controls the field excitation. Its function is to send charge into the battery. It is used in plants where the battery is not designed to take up load fluctuations, but is in service only to carry the peak of the load, being charged during periods of light loads and discharged in parallel with the dynamo.

The shunt booster acts *to increase the voltage applied to the battery so that the charging current will flow into the latter.*

Ques. How is the battery used with a shunt booster proportioned?

Ans. Usually sufficient battery is provided to carry the entire load during the light load period.

Ques. Explain the use of the rheostat controlling the field excitation.

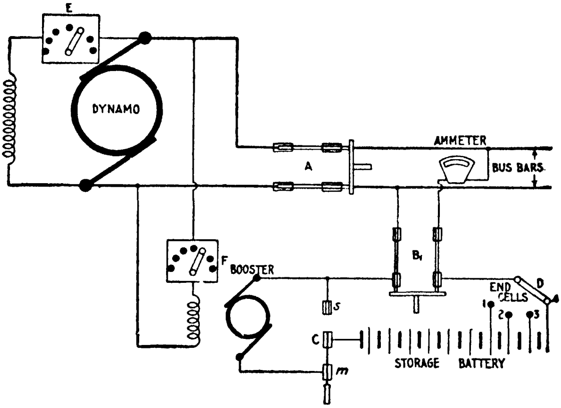

FIG. 1,652.—Diagram showing usual connections of a non-reversible shunt booster and battery system. In charging, the switches A and B, are closed, and C, put on contact *m*; the end cell switch D, is put on the last contact. Part of the dynamo current will go into the line and part through the booster into the battery. The charging current is adjusted by the field rheostat E. To discharge, throw the end cell switch D, to first contact; next turn switch C, to contact *s*. The battery is then in parallel with the dynamo with all end cells cut out. As the voltage of the battery falls, end cells are cut in by the end cell switch D.

Ans. It is used to vary the booster voltage so as to hasten the charging of the battery if desired.

Ques. For what service is the shunt booster not suited?

Ans. It is not adapted to circuits where there are sudden fluctuations that are great compared with the capacity of the dynamo.

Ques. What is its action in changing from charge to discharge?

Ans. It is not automatic, the switching must be done by hand.

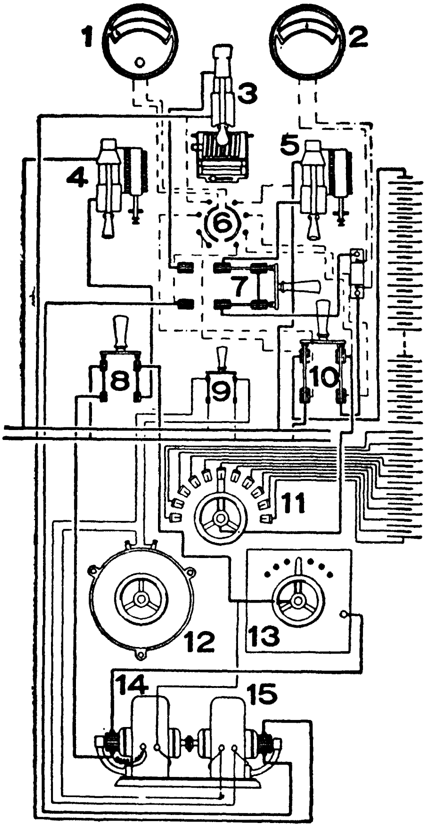

Fig. 1,653.—Shunt booster charge, and cell discharge. 1, volt meter; 2, ammeter; 3, under load circuit breaker; 4, booster motor circuit breaker; 5, battery circuit breaker, 6, volt meter switch; 7, booster switch; 8, booster motor switch; 9, booster field switch; 10, battery switch; 11, end cell switch; 12, booster field rheostat; 13, motor starter 14, motor; 15, dynamo

Ques. How may it be used reversibly?

Ans. It will give a pressure to assist the battery to discharge when excited from the bus bars and provided with a reversing rheostat.

In this case it will assist the battery to discharge when the direction of the field magnetization is changed. When so used, no end cells are necessary, but the booster must be run continuously during the entire period of discharge.

Ques. What should be the battery capacity on a 110 volt circuit with a reversible booster?

Ans. 56 cells will be sufficient.

The voltage to fully charge is $56 \times 2.6 = 146$, or 36 volts above dynamo voltage. Minimum voltage of discharge $= 1.8 \times 56 = 100$ volts, or 10 volts less than that of the line. Hence, the booster need give only 36 volts maximum, and is required to add 10 volts to the battery voltage toward the end of battery discharge. In this case the booster voltage is only $\frac{36}{49}$ or about ¾ of that required in the preceding case five cells less of battery are necessary and the end cell switches and leads are eliminated.

The machine will be larger, however than it would be if used only for charging, because the discharge is unusually greater than that of charge, and the current carrying of the armature must be great enough to take care of the heaviest currents.

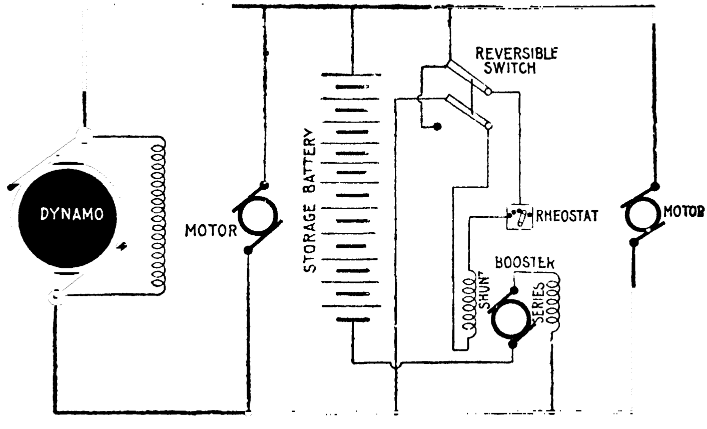

FIG. 1,654.—Diagram of compound booster connections.

Compound Boosters.—These machines are used on railway and power circuits where there are great fluctuations in load, the battery acting to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current.

The connections are shown in the diagram fig. 1,654. Under ordinary working conditions, the shunt field of the booster creates an electric pressure in the same direction as that of the battery, tending to discharge it.

When no current is flowing into or out of the battery, the following relation exists:

dynamo voltage = booster voltage + battery voltage.

In this case the dynamo carries the whole external load. If the load increase, the dynamo voltage decreases, so that the booster voltage + battery voltage is greater than the dynamo voltage, and the battery begins to discharge.

In discharging, the current passes through the series field of the booster and produces a proportional pressure acting with the shunt field to raise the voltage of the booster, thus increasing the battery discharge and shifting more of the load from the dynamo, until the system becomes balanced.

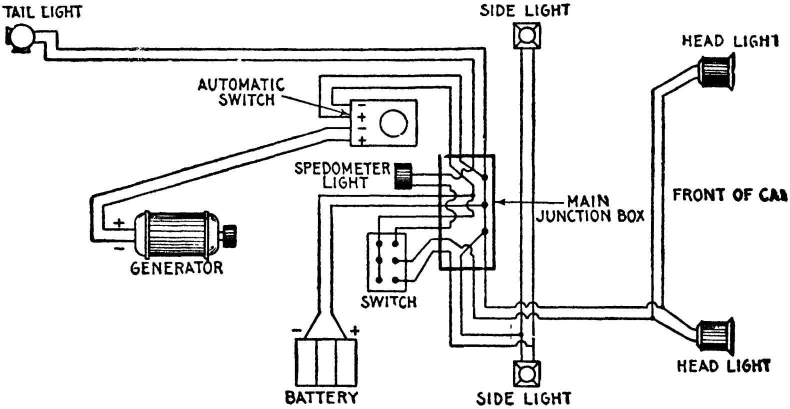

Fig. 1,655.—Diagram illustrating storage battery system, as applied to an automobile ior lighting.

If the load on the external circuit be small, the dynamo voltage rises and current flows into the battery. In this case the series field acts against the shunt field and decreases the booster voltage so that the pressure at the dynamo is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery until the load causes the dynamo voltage to drop to normal and the system is again balanced.

The battery and booster can be placed at the power house or where the greatest drop is likely to occur. As this system, like the series booster, depends for its action upon the drop of voltage with increase of load, it is only adapted to shunt wound dynamos.

From the foregoing description it will be seen that the compound booster is automatic within certain limits of battery charge. Any marked change of battery voltage will be followed by a corresponding change in dynamo current, unless the rheostat be manipulated to bring battery voltage + booster voltage back to normal.

While the theoretical dynamo current variation is small for a given change of load, there is always a sudden, momentary current rush from the dynamo on increase of load, the duration of which is equal to the time lag of magnetization of the booster field.

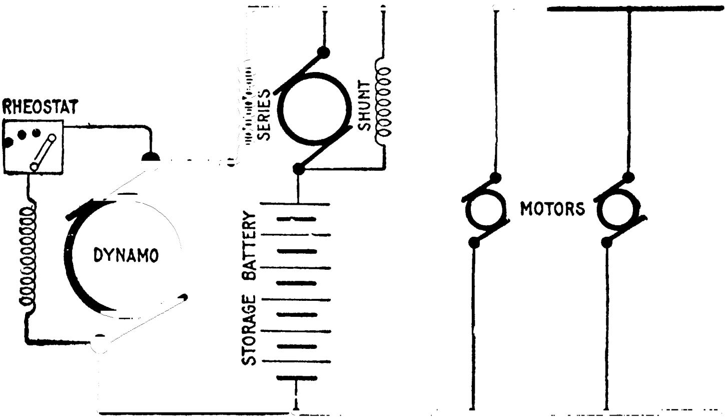

FIG. 1.656—Diagram of connection of one form of differential booster. *In operation*, the dynamo current passes through the series winding of the booster, and the current in this winding is to remain practically constant. The shunt coil produces a field which opposes the field produced by the series coil, the resulting magnetization being, in direction and amount, the resultant of the two field strengths. The adjustments are so made that when the normal dynamo current is passing through the series coil, the shunt field just neutralizes its effect, and the resultant magnetization is zero. Since the open current voltage of the battery is equal to that of the system, neither charge nor discharge takes place. With increased demand on the line, the slight increase in dynamo current in the series coil overpowers the shunt field, and causes a pressure in the booster armature in such direction as to assist discharge. If the external load fall below the average demand the current in the series coil decreases slightly so that the shunt field predominates, producing a booster armature pressure in a direction to assist charge. Although the voltage of the battery falls while discharging by an amount proportional to the outflowing current the increased excitation due to this current through the series coil is also proportional to it, and the booster voltage rises as that of the battery falls, their sum being always equal to that of the system. In other words, the booster serves to compound the battery for constant pressure.

Lights on a circuit with variable load will "wink" on sudden changes of load. In this respect the compound booster is not so satisfactory as the constant current booster, as in the latter *all* dynamo current passes through the series fields, which, by reason of their self-induction, oppose and check any sudden current rush, giving the booster field time to change its magnetization to the proper degree.

Differential Boosters.—In this type of booster, a series coil energized from the main current, tends to discharge the battery, and a shunt coil, excited from the battery, tends to charge the cells.

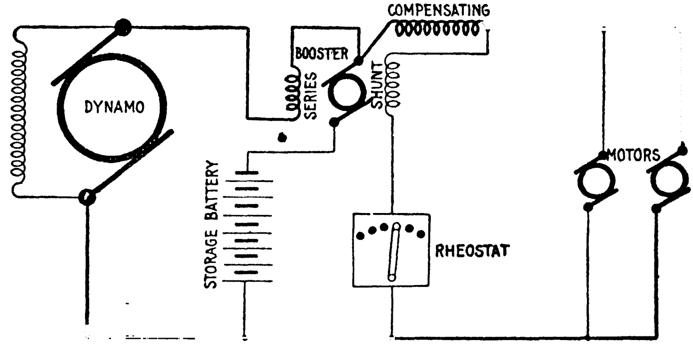

FIG. 1,657.—Diagram of differential booster system with compensating coil. ***In operation,*** the compensating field coil of the booster opposes the shunt coil and prevents the variation of the battery voltage disturbing the equilibrium of the system. If the battery pressure be lower than normal, it will not discharge rapidly enough to relieve the dynamo from overload fluctuations, unless the booster voltage be increased, and the dynamo will therefore have to supply a current greater than normal. If a current greater than normal flow through the compensating coil, the effect of the shunt coil opposed by the series coil is decreased, and the compensating coil, acting in the same direction as the series coil, causes a higher booster pressure tending to discharge the battery, and thus brings down the dynamo load to normal. Should the battery voltage be above its normal value, the battery would discharge too rapidly and carry more than its share of the load. In operating this system, the varying load must be beyond the booster equipment. The series and compensating coils may be temporarily short circuited so that the battery may be charged more rapidly.

These two coils are opposed to one another, and the difference in their respective strengths represents the net strength available for boosting. In order to produce quicker reversal, additional compound coils are sometimes added.

Ques. For what service is the differential booster adapted?

Ans. It is suited to power and railway circuits where the loads fluctuate widely and suddenly.

There are several varieties of this type of booster, and many patents have been issued covering the different methods of varying the voltage of the machine

Constant Current Boosters.—In installations where it is

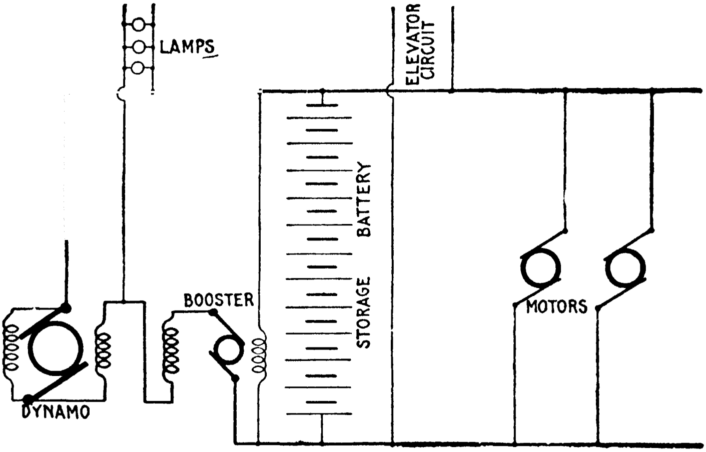

Fig 1,658 —Diagram of non reversible or constant current booster system The booster armature and field are in series between one side of the lighting and power bus bars A shunt field is also provided, which acts in opposition to the series field This booster carries a practically unvarying current from the lighting to the power bus bars, regardless of the fluctuations of the external load, which current is equal to the average required by the fluctuating load Except under abnormal conditions the shunt field always predominates giving a voltage which is added to that of the lighting bus bars, so that the voltage across the power buses is always higher than that across the lighting by an amount equal to the booster voltage If an excessive load come on the power circuits, the increased excitation of the series coil, due to a slight increase in current from the lighting to the power bus bars, lowers the booster voltage and consequently reduces the voltage across the power bus bars The battery discharges, furnishing an amount of current equal to the difference between that required by the load and the constant current through the booster. If the power load decrease below normal, the slight decrease in current in the booster series field increases the booster armature voltage and the excess current goes into the battery The booster, therefore, does not in reality give a constant current, but by proper design the variation may be kept within a few per cent desired *to supply both an approximately constant load and a fluctuating load from the same dynamos* (as for instance, in office buildings or hotels, where it is necessary to supply lights and elevators from the same source), *the fluctuations in the power circuits must not interfere with the lighting circuits and to prevent this, two sets of bus bars are provided.*

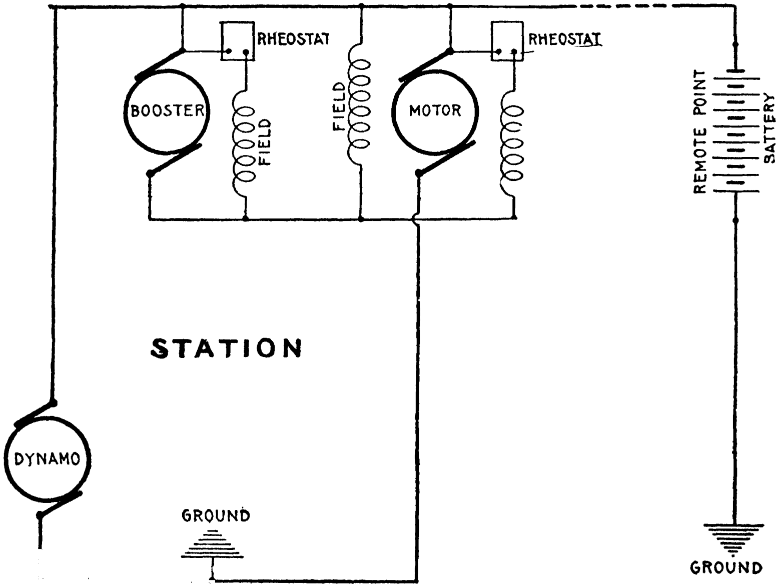

FIG 1,659 —Battery system with regulation for long feeders, for installation where it is desirable to locate the battery at a point remote from the station and avoid any equipment requiring constant attention at the battery end The compound wound motor, constant current booster is used and keeps constant the current flowing through the feeder, the battery taking up all load fluctuations.

The dynamos are connected in the usual manner to one set of bus bars, and the lighting circuits are connected across these. Across the other set of bars are connected the circuits supplying the fluctuating load, and the battery is also connected directly across these power bars.

The power bars are supplied with current from the lighting bars, a non-reversible or so called constant current booster being interposed between the two as shown in fig 1,658 Since this permits only a constant current to pass from the lighting bus bars, the load on the dynamo does not vary, although the load on the power buses may vary widely.

Separately Excited Boosters.—In some forms of booster the field excitation is secured by a small exciting dynamo. An example of this class is shown in fig. 1,660

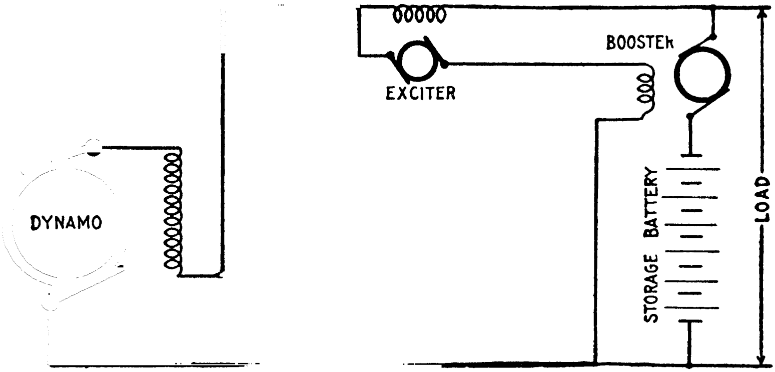

FIG. 1,660 —Hubbard's separately excited booster system (Gould Storage Battery Co) diagram showing general arrangement

The exciter is provided with a single series coil, through which the station output or a proportional part thereof passes The armature of the exciter is connected to the exciting coil on the booster, and thence across the mains as shown

With the average current passing through the field coil or the exciter, its armature generates a voltage which is equal to that of the system,

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NOTE —***Reversible boosters*** should be used where the average total current to the fluctuating load is greater than the battery discharge current and when the pressure of the power bus bars must not fall off with increase in load Electric railway and lighting plan having long feeders are examples of the systems to which reversible boosters are suited Non-reversible boosters should be used where the average total load is less than the battery discharge current, and where a drop in the voltage of the power bus bars is of advantage Examples of such plants are hotels or apartment houses where electric elevators are operated from the lighting dynamos Boosters are usually driven by electric motors directly connected to them though any form of driving power may be used and in opposition to it. These two opposing pressures balance, and no current flows in the booster field coils.

With an increase in external load above the average, the tendency is for an increase to take place through the exciter series coil, augmenting its field strength and consequently the exciter armature voltage. This latter now being higher than that of the line, causes current to flow in the booster field coil in such a direction as to produce a pressure in the booster armature which assists the battery to discharge, and is of a magnitude to compensate for the battery drop occasioned thereby.

When the load decreases below the normal, the current in the exciter field is decreased, and its armature voltage falls below that of the system. Current will now flow in an opposite direction in the booster field coil, generating a voltage in the booster armature to assist charge. Since the exciter always generates a voltage in opposition to that of the line, this system is known commercially as the counter pressure system.

TEST QUESTIONS

1. *What provision must be made in power plants when storage batteries are not used?*
2. *What is the effect of a battery connected in parallel with a dynamo?*
3. *What is understood by the expression "floating the battery on the line?"*
4. *Describe the connections and circuit control apparatus.*
5. *Name four methods of control for storage batteries.*
6. *Describe the regulation by variable resistance.*
7. *For what service is variable resistance suitable?*
8. *Describe an end cell switch.*
9. *How should the conductors joining the end cells to the end cell switch contacts be proportioned?*
10. *Describe some of the features of end cell switch construction.*

11. *Where are end cell switches of large capacity located?*
12. *What are reverse pressure cells used for?*
13. *Describe regulation with reverse pressure cells.*
14. *What is a "booster?"*
15. *Name six kinds of boosters.*
16. *How does a series booster act?*
17. *Describe the operation of shunt boosters.*
18. *For what service is the shunt booster not suited?*
19. *What is a reversible booster?*
20. *Describe the operation of compound boosters.*
21. *Describe the differential booster system.*
22. *For what service is the differential booster adapted?*
23. *What is a constant current booster?*
24. *How do separately excited boosters operate and for what service are they adapted?*

CHAPTER 42

Storage Battery Management

The Battery Room.—Precautions should be taken to prevent any direct sunlight falling on the battery cells in glass jars, as the breakage of such jars due to unequal expansion of the different portions of the glass, is a source of constant trouble and danger.

The exclusion of direct sunlight also tends to keep the evaporation of the electrolyte at a minimum.

Every battery room should be provided with a water tap and sink. The floor should be paved with vitrified brick, preferably blue or yellow in color, of diamond pattern and sloping in all directions toward suitable drains. A floor of this type can be easily washed by flooding with water, and its patterns tend to keep it dry under foot at all times. Wooden floors are rotted very quickly by acid spillings and by the spray.

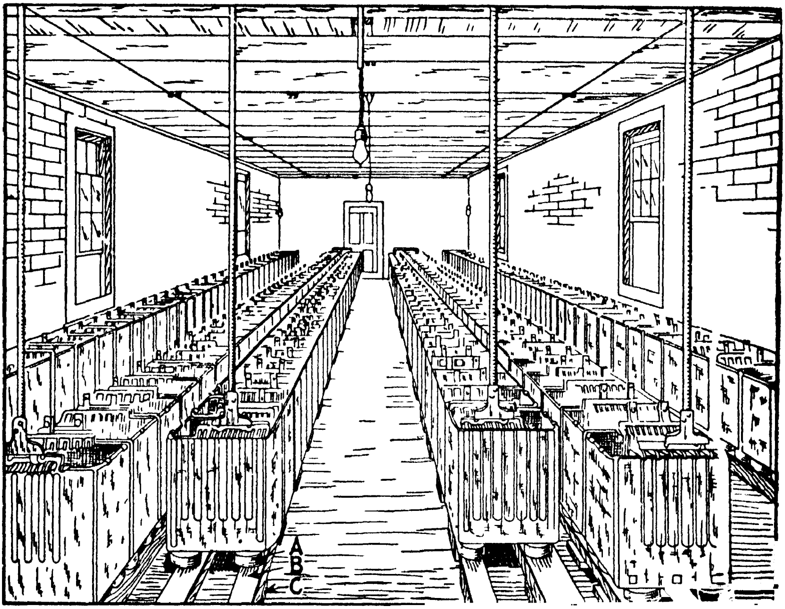
The room should be kept absolutely clear of everything which may be injured by the sulphuric acid fumes and it should be well ventilated to insure the safety and good health of the attendants.

A battery, even at rest, gives off hydrogen which when diluted with air forms a mixture which is very liable to explode if brought in contact with any kind of flame. Unless proper ventilation be provided, the breaking of the connection when a current is flowing, or the lighting of a bare flame lamp in the battery room would be dangerous.

Battery Attendants and Workmen.—Those employed in setting up batteries are liable to suffer from soreness of hands and the destruction of clothing unless proper precautions be taken to prevent the same. In order to avoid these troubles, the boots should be painted with paraffine mixed with an equal quantity of beeswax.

The clothing should be of woolen material, which, unlike cotton, is practically unaffected by the acid. If cotton shirts be worn, they should be dipped in a strong solution of washing soda and then rough dried.

An apron of sacking, backed with flannel should be worn over all the other clothes. A bottle of strong ammonia should be kept in the battery room at all times, and in case of an accidental splash of acid on the clothes, the immediate application of a small quantity of the ammonia, by means of the stopper, will at once neutralize the acid and prevent it burning a hole in the material.



1Fig. 1,661.—Interior of storage battery room showing arrangement of cells. A, are the cell insulators; B, wooden stringers; C, supporting pieces.

A pail containing water made strongly alkaline with washing soda should also be kept conveniently at hand during all operations in the battery room. The hands should be dipped occasionally in this water in order to prevent the skin smarting and becoming sore under the action of the acid.

If a splash of acid should happen to enter the eye, it should be washed at once with clean water, warm water preferably, and then put one or two drops of olive oil into the eye. If olive oil be not immediately available, any kind of engine oil is better than none at all.

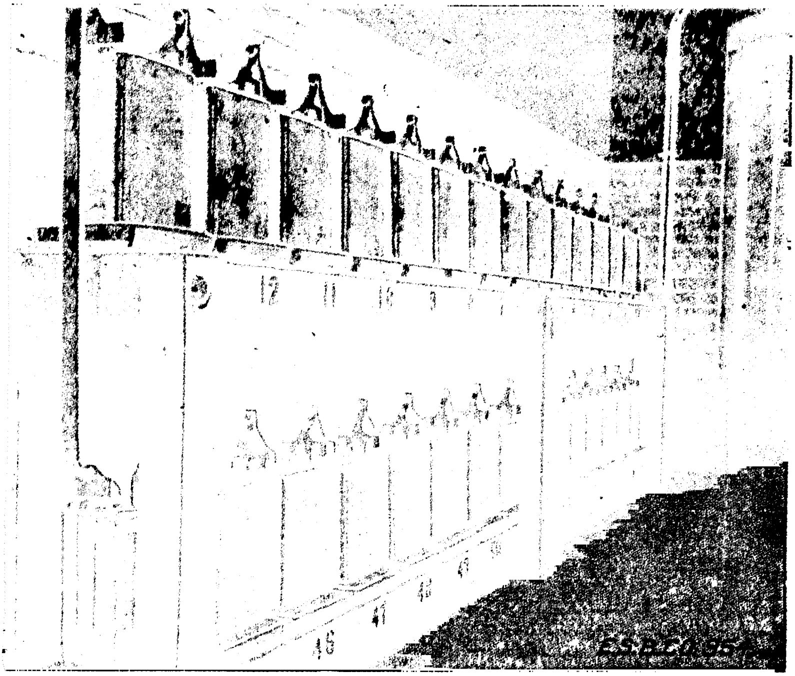


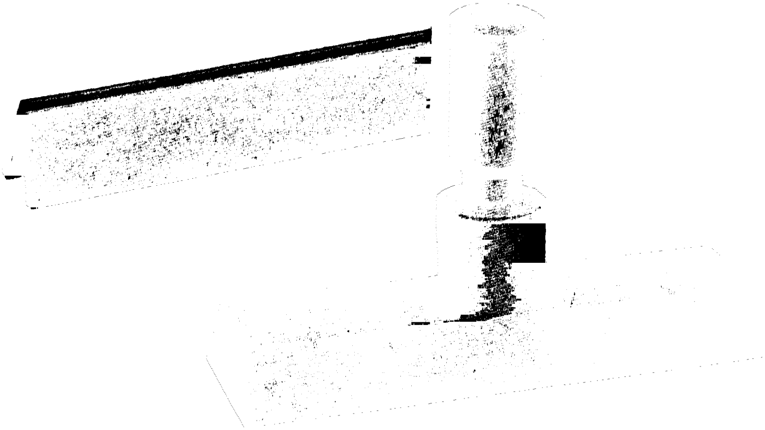
Fig 1,662.—Portion of a battery room showing Exide battery installed on two tier racks. On account of the increased weight of the elements and the higher discharge rates required of the type cells shown, the plates are shipped loose and the cells assembled on the ground; the plates are first placed in the jars and then lead burned to lead bus bars Bus bars used at the ends of rows are reinforced by copper bars embedded in the lead in order to provide ample conductivity to the terminal connectors

Points on Care and Management.—In setting up storage cells, they should be placed in as few tiers as possible, and in such a manner that the direct rays of the sun are not allowed to fall upon the cells.

The rays of the sun are likely to crack the glass. This is probably due to the unequal expansion of the glass, for it has been found that jars which are carefully annealed never crack in this manner. Of course, the latter precaution does not apply to large batteries, where lead lined wooden tanks or solid lead boxes are used.

In installing plants where expert attendance is not to be had, it is well to place in the circuit two magnetic cut outs, one set for maximum current, and the other for minimum voltage, so that the battery cannot be discharged too low.

Ques. How should the cells be placed?



Figs. 1,663 and 1,664.—Exide bars used with type cells shown in fig. 1,662.

Ans. They should be placed as shown in fig. 1,669, on insulators A, resting on wooden stringers B, and supporting pieces C, placed on the floor.

The insulators are usually of glass or porcelain, which in certain patterns may be filled with oil, to insure better insulation as shown in figs. 1,169 and 1,670.

In setting up a battery, it should be remembered that plates deteriorate on standing exposed to the air. They should, therefore, be unpacked and set up immediately on arrival. When they are entirely connected up, they are ready for the addition of the electrolyte, and for the forming charge, which they should receive immediately.

Ques. How should the wooden stringers, shelves, cell boards, and trays be treated?

Ans. They should be thoroughly varnished to insure cleanliness as well as good insulation.

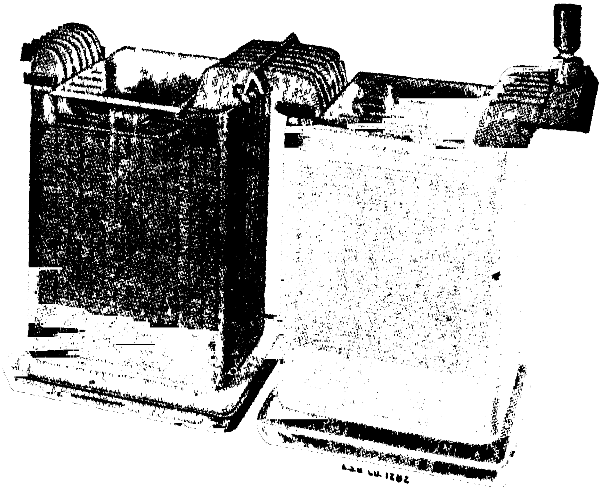


Fig. 1,665 —Two complete Exide glass jar cells at end of a row. The illustration is intended to show the application of the two type bus bars, illustrated in figs 1,663 and 1,664. ***In assembling,*** the elements (positive and negative groups and separators) are assembled in glass jars and supported by lugs resting on the top of the jar The jars are set in sand, contained in glass sand trays, in order to distribute the weight, and the cells thus assembled are set on wood racks Connections between cells are made by bolting together the tails provided for that purpose on the group straps

Outside of each cell and close to the mouth, melted paraffine should be applied by means of a brush, so as to form a band about an inch wide, for the purpose of preventing the electrolyte creeping over the top of the jar, wetting the outside, and thereby impairing the insulation.

Ques What should be done to avoid waste of current by leakage?

Ans. Each cell of the battery must be thoroughly insulated.

Ques. What is the effect of verdigris which forms on the terminals?

Ans. It is a poor conductor and should therefore be removed and the terminals kept bright and clean to insure the proper flow of the current.

Ques. What precautions should be taken in unpacking cells?

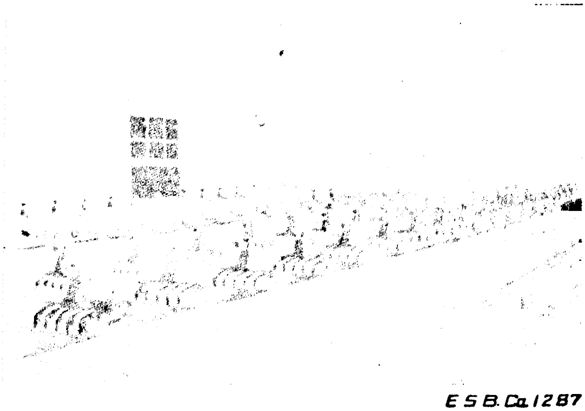


FIG. 1,666.—Interior battery house Boston, Cape Cod and New York Canal Co., Buzzards Bay, Mass.

Ans. The plates should be handled carefully.

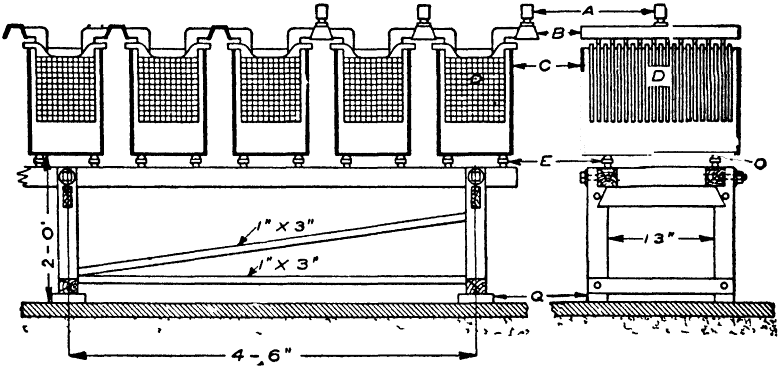
When they are sent out from the factory already built into sections, they should be unpacked without disturbing a single plate. In all cases, every particle of packing, straw, hay and any chips and bits of parts should be carefully removed, and all the dust should be blown out of the spaces between the plates by means of a bellows or other similar device.

Although such particles are good insulators, the action of the sulphuric acid electrolyte carbonizes them, reducing their resistance which tends to produce leakage.

Ques. How should the cells be assembled?

Ans. In placing the plates or plate sections in the containing jars or tanks, care should be taken to see that the supporting frame of paraffined wood bears evenly on the bottom of the jar.

If not, wedges of paraffined wood should be placed under the



FIGS 1,667 and 1 668 —Views of battery cells and stand A, cable lugs, B bus bars, C, glass tanks D, plates, E, glass insulators, Q, vitrified brick, O, lead washers Battery cells are set up on stands the one shown being built for a 100 ampere battery Larger sizes would, of course require heavier stands and if space be limited the cells may be set in rows, one above the other However, it is evidently much better to place the cells in single rows, where they will be convenient for inspection and repairs or any work that has to be done on them There are several other ways of setting a battery one of which is to place the stringers on the floor, on vitrified brick or some other insulator and then place trays filled with sand on the stringers, setting the cells in the trays on glass insulators

frame, so as to distribute the weight of the section equally Each section should be lowered gently into the jar until it rests fairly upon the frame, and care should be taken to see that none of the plates have shifted, and that the section is situated centrally in the jar, with a small clear space all around

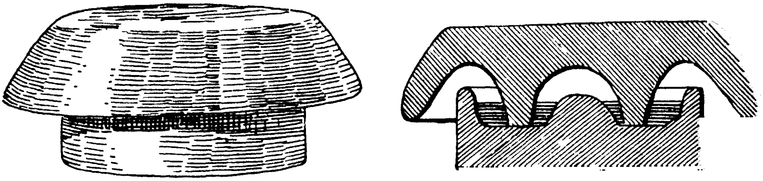
Ques. How should the cells be arranged?

Ans. They should be so placed that the battery attendant can see the edges of the plates and consequently the spaces between them at the same time.

Ques. Describe the method of connecting the cells.

Ans. This is accomplished by means of solder, bolts and nuts, or clamps, according to circumstances.

The use of solder is not essential if there be a good surface of the lead strip of one cell in contact with that of the next, and provided these contact surfaces have been well cleaned. Usually, the ends of the lead strips are turned up so that the junction of two cells takes the form of an inverted T.



FIGS 1,669 and 1,670 —Oil insulator, fig. 1,669, general view; fig 1,670, sectional view Whenever a number of open cells are in use, unless precautions be taken, electrical leakage between the cells invariably occurs This leakage is due chiefly to the semi-conducting nature of the thin layer of moisture which frequently covers not only the glass containing cells, but the unimmersed parts of the elements, and even the shelves on which the cells rest. To prevent this waste of energy, the outside of the cells should occasionally be well cleaned and thoroughly dried A little vaseline or tallow may then be rubbed over them to advantage The shelves of supports for the cells, should either be well varnished or coated with paraffin wax. Electrical leakage is greatly reduced if each cell be mounted on a glass or earthenware insulator, as shown in the illustrations The insulator here shown is in two parts and of a mushroom shape The lower cup contains a small quantity of some non-evaporating oil, and as the conducted moisture cannot bridge across this, a nearly perfect insulating medium is obtained These insulators are made in various sizes and may be obtained in earthenware or glass. Those made of glass are found to give the best results

Ques. What precaution should be taken in joining the terminals of the cells?

Ans. The contact at the junctions should be very thorough, otherwise they will become heated when a current is flowing, and it is desirable that the connections should include as little lead strip in the circuit as possible, thereby reducing the amount of useless resistance.

Brass or gun metal clamps may be kept clean by brushing them over with melted paraffin after they have been screwed up tightly. When thus treated they serve to indicate points of bad contact by heat, generated at such points, when the current is flowing, softening the paraffin and changing its normal color.

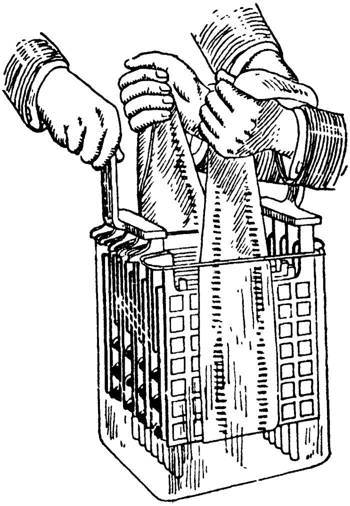


Fig. 1,671.—Illustrating method of placing plates in glass jars.

NOTE.—*The battery room* should be dry, clean, well ventilated and free from metal work, also neither too hot nor too cold. Too high a temperature in the battery will shorten the life of the plates, and although there is no danger of the battery freezing, a low temperature, while it is maintained, reduces the capacity; otherwise cold has no ill effect on the battery. A good temperature for the battery room is about 60° F. A damp, dirty room is conducive to grounds and surface leakage, and there is danger of impurities getting into the cells. If the room be very damp the electrolyte may absorb enough moisture to cause the cells to overflow. Strong floors are necessary to support a battery, as one of a 100 ampere, 125 volt capacity weighs from 12 to 13 tons. A wood floor may be used, but a cement floor is better, and a glazed vitrified brick floor is better still. Wooden floors will rot quickly from the acid, which is sure to get on it more or less; a cement floor will be disintegrated if too much acid get on it. This kind of floor forms a first class ground if there be any chance for one; the glazed brick floor is not affected by the acid and is an insulator

Vaseline and different kinds of anti-sulphuric acid varnishes, or preparations that are not attacked by the electrolyte, may also be used for this purpose. It is a good plan to color the varnish with vermilion or lamp black and paint the positive connections red and the negative connections black, and also other parts of the installation for distinguishing the polarities.

Condensed Rules for the Proper Care of Batteries.—The following general instructions should be followed in the care and maintenance of batteries:

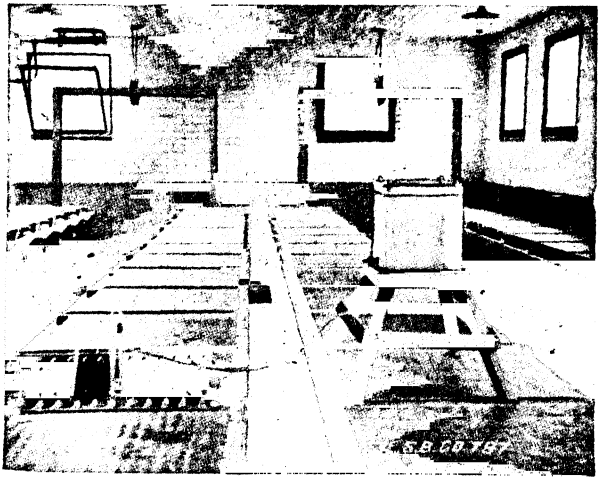


FIG. 1,672.—Michigan Central Railway, Welland draw battery. View of the battery room showing automatic pilot cell filler.

NOTE.—***Peroxide of lead, pure oxide or plumbic dioxide*** is the true active material in all forms of lead storage cell. This lead salt is found native as the mineral plattnerite. It is a heavy lead ore, forming black, lustrous, six sided prisms. It may be prepared from the red oxide by boiling it in fine powder, with nitric acid diluted with five parts of water, or by treating the carbonate when suspended in water with a stream of chlorine gas, and then thoroughly washing and drying it. It is reduced to a lower oxide on heating or by exposure to bright sunlight. This salt readily imparts oxygen to other substances; it becomes heated to redness when thrown into sulphuric dioxide, and takes fire when triturated with sulphur—hence this oxide is a common ingredient in lucifer match composition. When used in primary or secondary batteries it readily imparts its oxygen to nascent hydrogen, forming water, and thus it acts as a powerful depolarizer. When robbed of its oxygen, it readily becomes reoxidized, if subjected to the action of nascent oxygen liberated by the electrolytic decomposition of water.

1 A battery must always be charged with "direct" current and in the right direction

2 Be careful to charge at the proper rates and to give the right amount of charge, do not undercharge or overcharge to an excessive degree

3 *Do not bring a naked flame near the battery while charging or immediately afterwards*

4 Do not overdischarge

5. Do not allow the battery to stand completely discharged

6 Voltage readings should be taken only when the battery is charging or discharging, if taken when the battery is standing idle they are of little or no value

7 Do not allow the battery temperature to exceed 110° Fahr

8 Keep the electrolyte at the proper height above the top of the plates and at the proper specific gravity Use only pure water to replace loss by evaporation

9 In preparing the electrolyte *never pour water into the acid*

10 Keep the cells free from dirt and all foreign substances, both solid and liquid

11 Keep the battery and all connections clean, keep all bolted connections tight

12 If there be lack of capacity in a battery, due to low cells, do not delay in locating and bringing them back to condition

13 Do not allow sediment to get up to the plates

14 Keep the tops of closed batteries clean

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*NOTE —***The voltage increase or decrease** with change in current is practically constant in a given type of cell for any size of cell when the current is referred to a given time rate of charge or discharge that is the drop in a large cell or in a small cell when each is discharged at its four, six or eight hour rate, will be the same The drop varies somewhat for the condition of the battery charge

NOTE —***How to prevent lead poisoning.*** Workmen employed in the manufacture of lead or lead salts are always liable to lead poisoning both by inhaling the dust and by contact of the materials with the hands Various preventives for this have been employed, and of these, the most simple seems to be a careful washing of the hands in petroleum It is said that three washings a day are sufficient to prevent all serious danger of poisoning The benzole in the petroleum appears to scour the skin and remove the loose lead dust and the fatty substance in the oil fills up the pores of the skin and prevents the absorption of the deleterious salts The employment of petroleum has given such good results that it has been proposed to use this material as a guard against poisoning in other industries where the salts of copper or mercury are employed

TEST QUESTIONS

1. *How should cells be placed in a battery room?*
2. *How should the wooden stringers, shelves, cell boards and trays be treated?*
3. *What should be done to avoid waste of current by leakage?*
4. *What is the effect of verdigris which forms on the terminals?*
5. *What precaution should be taken in unpacking cells?*
6. *How should the cells be assembled?*
7. *How should the cells be arranged?*
8. *Describe the method of connecting the cells.*
9. *What precaution should be taken in joining the terminals of the cells?*
10. *What should be the condition of the battery room?*
11. *What kind of preparations are not attacked by the electrolyte?*
12. *Give fourteen rules for proper care of battery.*
13. *How may lead poisoning be prevented?*
14. *What is the nature of peroxide of lead, pure oxide or plumbic dioxide?*

CHAPTER 43

Storage Battery Troubles

To successfully cope with faults in storage batteries, there are two requisites:

1. A thorough knowledge of the construction and principle of operation of the battery, and

2. A well ordered procedure in looking for the source of trouble.

The faults which are usually encountered by those who operate storage batteries are here given.

Short Circuits.—A short circuit may arise through any of the following causes:

1. Through direct contact between adjacent plates.
2. Through some conducting material such as a piece of lead, solder, spongy lead, or oxide of lead sticking between the plates.
3. Through direct or indirect contact with the lining of the tank, if lead lined tank be used.
4. Through foreign particles such as wood, straw, fibre, plaster, etc., getting into the cells.
5. Through unintentional touching of lugs on adjacent plates.
6. Through the accumulation of sediment in the bottom of the jar or tank.
7. Occasionally fine particles which are not noticeable at first may bridge across, grow larger, and become short circuits.

It is of importance for the satisfactory working of the cells that positive and negative plates, and all parts of the same, should be completely insulated from one another.

When a short circuit is sufficiently large to allow the discharge of the cell to pass through it, the elements will get into an unhealthy condition.

The indications of a short circuit are low voltage, low specific gravity, and the failure of the cell to gas at the end of the charge.

As soon as the condition of the cell indicates a short circuit, it should be given attention immediately, and the trouble remedied by removing the short, after which the cell should be fully charged before again being put into service.

Should the operator suspect trouble with his battery he may discover a short circuited cell by the marked difference in color of the plates or in the specific gravity of the electrolyte, as compared with the other cells. No particular damage will be done, if the trouble be discovered and removed before these symptoms become too marked.

If a foreign substance has become lodged between the plates, it may be removed by a wooden or glass instrument.

If some of the active material has scaled off, it may be forced down to the bottom of the jar. If excessive sediment be found, the jar and plates should be washed carefully, and reassembled.

Short circuits usually occur through the giving way of the wood separators between the positive and negative plates. The causes of this may be:

1. Age of the battery;

2. The solution allowed to fall below the top of the plates, in which case the separators will dry and crumble.

It is of vital importance in a battery to have the separators in good condition, and unless a battery be new it will be found advisable to install new wood separators whenever a cell is dismantled for repairs.

A short circuit in a cell is indicated when it becomes dead and the solution cannot be brought up to its proper density by charging, or when the cell will not hold its charge. Sometimes, if the separators be renewed, the cell will continue to give service. This can be generally determined by an examination of the plates. If the plates be hard and solid they can probably be used again. If they be soft, pitted and crumbly, new plates should be installed or a new battery furnished.

FIG. 1,673.—Damaged element from a "slopper" battery. *If elements be loose* in the jars or case be not held down firmly, the jolting of the car will cause the plates to jump around, breaking the sealing compound and causing the paste to fall out.

Willard Trouble Chart

CAUSE SYMPTOMS	Battery Undercharged.	Battery Overcharged.	Battery Neglected no Water Added.	Too Much Water Added When Filling.	Battery Accidentally Emptied of Solution.	Battery Badly Sulphated.	Battery Reversed in Charging.	Battery Completely Discharged.	Leaky Jar.	Acid Spilled on the Connections.	Broken Connections Between Generator and Battery—Terminals Loose.	Battery Worn Out.	Short Circuit Between Plates.	Generator not Charging Properly.	Short Circuit in the Wiring.
Gravity Less Than 1.215	AJ										O			O	O
Very Low Gravity or no Reading Obtainable on Hydrometer.	A			A		AML	AL	A			IJ		BD	O	G
No Solution in Cell			ML		FD				CDL						
Battery will not take Charge						ML					IJ	N	BD	O	O
Battery Charged one Day Discharged Over Night												DN	BD		GI
Battery will not Crank Engine	A		AML		FAD	AML	AL	A	CDL	IJ	J	N	BD	O	O
Battery Box Wet or Rotted				HE					CDH						
Battery Very Hot		K												KJO	
Terminals Corroded										HI					
Lights Flare Up and Sometimes Burn Out											OJ				

Leaky Jars.—If the solution be found to be markedly lower in one cell than in the other cells, it indicates that the solution has spilled due to failure to tightly replace the vent plug after filling, or that the jar has developed a leak.

When this condition obtains, the cell should be filled to the proper height with pure water and the battery should be watched carefully to determine the cause. If the questionable cell continue to lose solution to a greater extent than do the other cells, it is sure evidence of a leaky jar. This jar should be replaced at once to prevent damage to the case.

Ques. What causes low specific gravity when there are no short circuits?

Ans. 1, sloppage or a leaky jar (the loss having been replaced with water alone), 2, insufficient charge, 3, over discharge, or 4, a combination of these abuses. Any of these mean that there is acid in combination with the plates.

In this case the acid should be brought out into the electrolyte by a long charge at a quarter of the normal discharge rate.

REMEDY

A. Needs charging.
B. Needs reinsulation.
C. Replace jar.
D. Have work done by Willard Service Station or a good battery man.
E. Fill only to ½ inch above plates.
F Let experienced battery man replace the electrolyte.
G. Go over the wiring system to find the leak.
H. Clean battery and the inside of battery compartment with cloth moistened in ammonia; this will neutralize acid.
I. Clean and grease terminals with vaseline.
J. Tighten terminals and all connections
K. Burn all lights.
L. Give long charge at low rate.
M. Add water.
N. If in service for four years replace with new battery.
O. Take car to motor car dealer for readjustment and for testing.

NOTE.—*Remedy.—To accompany Williard Trouble Chart.*

Besco Trouble Chart

ELECTROLYTE	LOW GRAVITY	OVERCHARGING OVER DISCHARGING SPILLING BROKEN OR LEAKY JAR	Low gravity denotes insufficient volume of acid. If there is no other trouble such as broken or leaky jars, charge the battery to its highest point. Add 1.400 acid until the hydrometer test reads between 1.275 and 1.300.
	HIGH GRAVITY	EVAPORATION OF WATER UNNECESSARY ADDITION OF ACID	Gravity reading higher than 1.300 is dangerous to the battery. To correct high gravity, empty solution from cells, replace with 1.100 electrolyte. Give the battery a full charge, then adjust gravity to read 1.275 to 1.300. Replace evaporation with distilled water.
SEP.	WORN THROUGH	BUCKLING OF PLATES NATURAL WEAR	The only cure for defective separators is to replace them with new ones.
	TREEING	NATURAL GROWTH OF MATERIAL	
JARS	LEAKY BROKEN	VIBRATION SUDDEN JAR BATTERY NOT HELD SOLID IN PLACE	Broken or leaky jar must be replaced or plates will sulphate and harden.
CASE	ROTTED	SLOPPING EXCESSIVE GASSING OR BOILING	Acid slopping on wood case will rot them and at the same time ground, or short circuit the battery. Rotted wood boxes will expose the rubber jars, loosen the parts, and subject the plates to undue vibration, loosening the active material. The battery should be firmly anchored in place by holddowns.
CON.&TER.	BROKEN CORRODED	BATTERY LOOSE ON CAR DEFECTIVE LEAD BURNING CORROSION DUE TO SLOPPING	Repair all broken connections. Tighten all terminals. Clean off corrosion with ammonia or soda, grease with vaseline.

Besco Trouble Chart—*Continued*

PLATES	**SULPHATION**	ELECTROLYTE BEING LOW	Broken or Leaky Jar Evaporation Slopping of Solution	First Correct mechanical faults. Then give the battery a long slow charge at the 24-hour rate. Do not permit the battery to gas violently or overheat. If the battery is disassembled, scrape the sulphate from the plates slightly with a small piece of wood.
		OVERDISCHARGED		
		STANDING IN A DISCHARGED CONDITION		
		ADDING 1.300 ACID TO REPLACE EVAPORATION		
		LOCAL ACTION		
	BUCKLING	OVERCHARGED	Charging Rate too High Charging Battery When Full	Buckled plates can generally be straightened in a plate press or vise. To eliminate the tendency for the grids to crack and loosen the active material, first charge them. This softens the plate. Thoroughly wet the plate with water. Do not press dry plates. It is necessary to place boards of proper thickness between the plates. Apply pressure gradually—avoid unnecessary strain.
		OVERDISCHARGED	Discharging Rate too Great Using Battery When Discharged	
		OVERHEATING DUE TO OVERCHARGING		
		SULPHATING		
		SHORT CIRCUIT	Faulty Separators Sediment in Bottom of Jar Starting or Lighting System Shorted	
	SHEDDING OF ACTIVE MATERIAL	OVER CHARGING		Usually the positive plates shed the active material first. If they are too far gone, it is necessary to renew the positive groups with new plates. It is also advisable to renew the separators at the same time. Clean out sediment before assembling the battery. If the plates have not become too solid or lost a greater part of their porosity, several complete charges and discharges will restore them to activity.
		OVER DISCHARGING		
		AGE OF THE BATTERY		
		SULPHATING		
	HARDENING OF NEGATIVE PLATE	LONG PERIOD OF IDLENESS		
		AGE OF THE BATTERY		
		ELECTROLYTE LOW		
		EXPOSURE TO AIR		

Worn Out Plates.—If the solution in the cells can quickly be brought up under charge to the proper density and only a small capacity can be obtained on discharge, the battery is worn out, due to age or indifferent material in the plates.

The above applies to a battery under test and not on the car, as in the latter case there may be faults in the lighting and starting system, causing a leak from the battery or causing the battery to receive insufficient charge.

A cell that has been short circuited may be disconnected from the battery and charged and discharged several times separately which may remedy the trouble.

Plates that are fully charged are in the best condition for examination and repairing. If some of the plates are to be discarded, eliminate any short circuits and give the battery a preliminary charge before working on the plates.

Ques. How are internal short circuits indicated?

Ans. Short circuits in a cell are indicated by short capacity, low voltage and low specific gravity, excessive heating and evaporation of the electrolyte.

Ques. How are internal short circuits located?

Ans. If the trouble cannot be located by the eye, the battery should be connected in series and discharged at the normal rate through suitable resistance. If a suitable rheostat be not available, a water resistance may be used.

This consists of a receptacle (which must not be of metal) filled with very weak acid solution, or with salt water in which are suspended two metal plates, which are connected by wires through an ammeter. The current may be regulated by altering the distance between the plates, or by varying the strength of the solution. As the discharge progresses the voltage will gradually decrease, and it should be frequently read at the battery terminals; as soon as it shows a sudden drop, the voltage of each cell should be read with a low reading volt meter.

While the readings are being taken, the discharge rate should be kept constant and the discharge continued until the majority of the cells read 1.70 volts; those reading less should be noted. The discharge should be followed by a charge until the cells which read 1.70 volts are up, then the low cells should be cut out, examined, and the trouble remedied.

Over Discharge; Buckling.—On account of unequal expansion of the two sides of a plate, or certain portions thereof, the strains thus set up may distort it and cause it to buckle or warp.

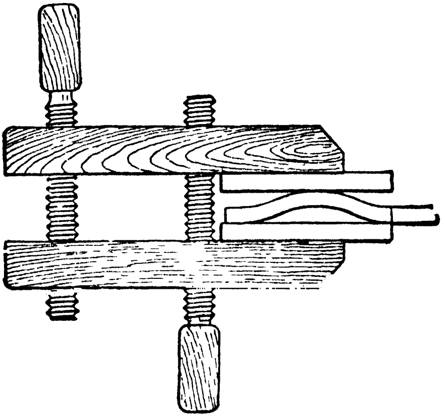


FIG. 1,674.—Method of straightening a buckled plate. ***Buckling*** is caused by the unequal expansion of the plates which is due to the sulphate lodging on the plates, thus preventing action taking place at that point; and by excessive charging. If the plates be not badly buckled, they can be placed between 2 boards and with a little pressure can be straightened out.

Buckling is always due to over discharge on either the whole, or some portion of the plate. Occasionally buckling may occur with too rapid charge and discharge.

Sulphation of Plates.—During discharge a storage cell deteriorates *on account of the formation of* ***lead sulphate*** *over the surface of the plates.*

This lead sulphate is the product of the chemical combination of active material with the electrolyte. It is an insulator, white in color and of greater volume, in proportion than the active material.

When the discharge is over prolonged, sulphation is evidenced by the electrodes becoming lighter in color, because of the sulphate which lessens the active surface.

Ques. Name some causes of sulphation.

Ans. It is sometimes caused by a too weak or too strong acid solution, but more generally by continued over discharging, or too rapid discharging of the batteries, or by allowing them to remain uncharged for long periods of time.

Ques. What is the effect of sulphation?

Ans. It tends to cause shedding of the active material, buckling of plates, loss of capacity, increase of resistance and consequent reduction of efficiency, and increase of temperature with flow of current. A sufficient amount of lead peroxide and sponge lead must be retained on the plates to reduce this resistance, otherwise the charging current cannot flow through the active material and regenerate the battery.

Ques. What should be done in case of sulphation?

Ans. Charge the battery below the maximum rate, necessarily prolonging the charge, until the plates assume the proper color. This is a tedious task, but it must not be hastened, as rapid charging will cause serious buckling.

NOTE —***How to destroy acid vapor in storage battery rooms.*** The best remedy is a good system of thorough and rapid ventilation, failing this the evil effect of the acid may be minimized by the fumes of a powerful alkali such as ammonia, which will readily combine with the sulphuric acid to form sulphate of ammonia, an inert and harmless salt If the use of liquid ammonia be objectionable, the granulated carbonate of ammonia will do equally well The ammonia fumes are best obtained by placing dilute ammonia in shallow dishes, so that an extensive evaporating surface is obtained In the same way the corroding dew which is so frequently deposited on the lugs and connectors of storage battery elements may readily be neutralized by the application of a solution of ammonia, or even common washing soda A good method of protecting metal work in battery rooms is to smear it over evenly with vaseline

The charging should be done at low rates. Discharge should not be carried below 1.8 volts per cell, and the charging current should be stopped when each cell shows 2.4 volts

If the plates be in a very bad condition, a little of the white sulphate deposit on each of the positive plates may be removed with a stick, thus exposing a part of the good surface to the action of the electrolyte.

FIG. 1,675.—Example of badly buckled plates.

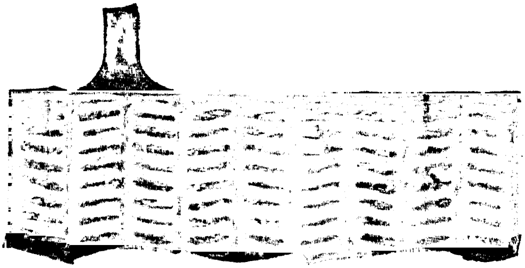


FIG. 1,676.—Effect of over discharge in bulging out the active material.

If the positive plates cannot be restored to their proper color as directed, it is cheaper to replace them by a new set, rather than to attempt their recovery by means of reversals.

Lack of Capacity.—This is usually due to the clogging of the pores in the plate with sulphate which is invisible because the surface of the plate is maintained in proper condition but the interior portions of the active material have not been thoroughly reduced. To correct this condition, the battery should be given a prolonged overcharge at low current rates, say about one fourth the normal 8 hour charging rate.

Positive cells are sometimes considered defective if the cells will not take a charge or they show lack of capacity, especially if they seem to be hard. This condition is sometimes due to new separators which have not been allowed to become saturated with electrolyte before starting the first charge.

Ques. What action takes place when a battery stands idle for some time?

Ans. It loses part of its charge, due to local losses in the cells.

Ques. How should batteries be treated, when used but occasionally?

Ans. If a battery is not to be used for several days, it should first be fully charged before standing, if it continue idle, a freshening charge should be given every two weeks, discontinuing the charge when the cells begin to gas freely.

NOTE.—***Oxide of lead, litharge, or plumbic oxide*** is sometimes found native as lead ochre, and may be artificially made by heating the carbonate or nitrate. It is usually prepared on a larger scale by heating the lead in air. When the metal is only moderately heated, the oxide forms a yellow powder which is known as massicot, but at a higher temperature the oxide melts, and on cooling, it forms a brownish scaly mass, which is called flake litharge. The scaly pieces are afterwards ground between stones under water, forming buff or levegated litharge. The litharge of commerce often has a reddish yellow color, due to the presence of some of the red oxide of lead, and frequently from one to three per cent. of finely divided metallic lead is found mixed with it. When heated to dull redness litharge assumes a dark brown color, and becomes yellow again on cooling. At a bright red heat it fuses and readily attacks clay crucibles, forming silicate of lead. Litharge is a most powerful base, and has a strong tendency to form basic salts. Hot solution of alkalies, as potash or soda, readily dissolve it, and on cooling crystalizes out in the form of beautiful pink crystals.

Ques. What should be done in case of lack of capacity?

Ans. If the current consumption be normal, there may be poor connections or trouble in the battery; there may be a dry cell, due to a leaking jar; some or all of the cells may be in a state of incomplete charge, due to the battery having been run too low and not sufficiently charged, or the plates may be short circuited, either by the sediment (deposit in the bottom of the jar) getting up to the bottom of the plates or by something that has fallen into the cell.

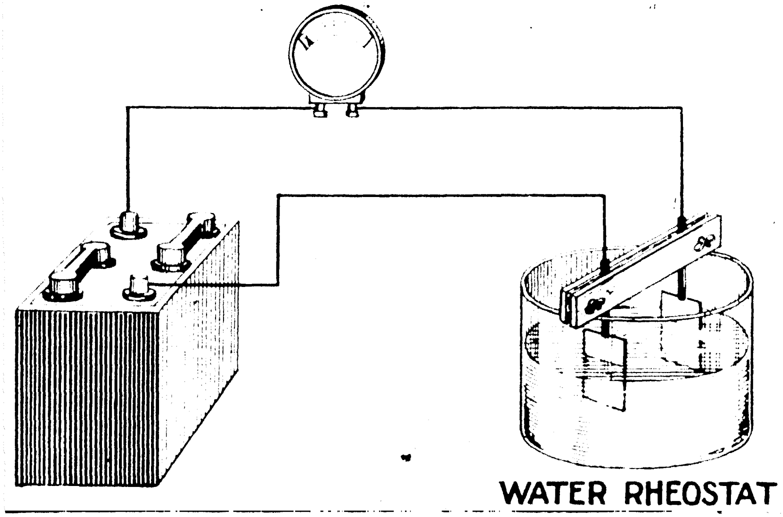


FIG. 1,677.—Home made water resistance or rheostat for discharging battery.

Positive plates should be examined for buckling (warping) and washing out of the material. If the plates be buckled so much that the element will not go back into the jar they must be discarded. Negative plates are not affected by abuse as readily as the positives. In the last stage of extreme sulphation of negatives in which the material deteriorates into what may be described as a mushy condition, usually resulting from adding acid to the cells, there is no treatment known that will restore cells which have been abused in this manner.

Manifestations of Proper and Improper Battery Operation.—It is easy to determine the condition of the battery by looking at it, assuming the observer know what to look for. In examining a new battery fully charged, the following will be noted:

1. There will be a little sediment in the bottom of the jars, but not much more than the thickness of a piece of paper. This may be white, gray, light brown or dark brown, but in any case it is of no consequence. The electrolyte should be at the proper height in all of the cells, that is about half way between the tops of the wood separators and the bottoms of the covers.

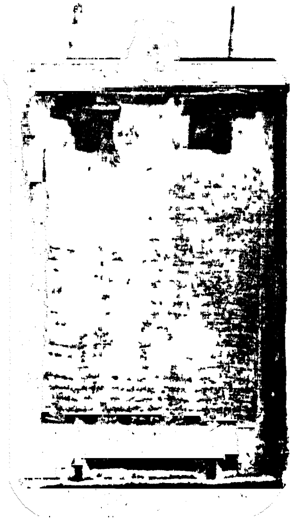
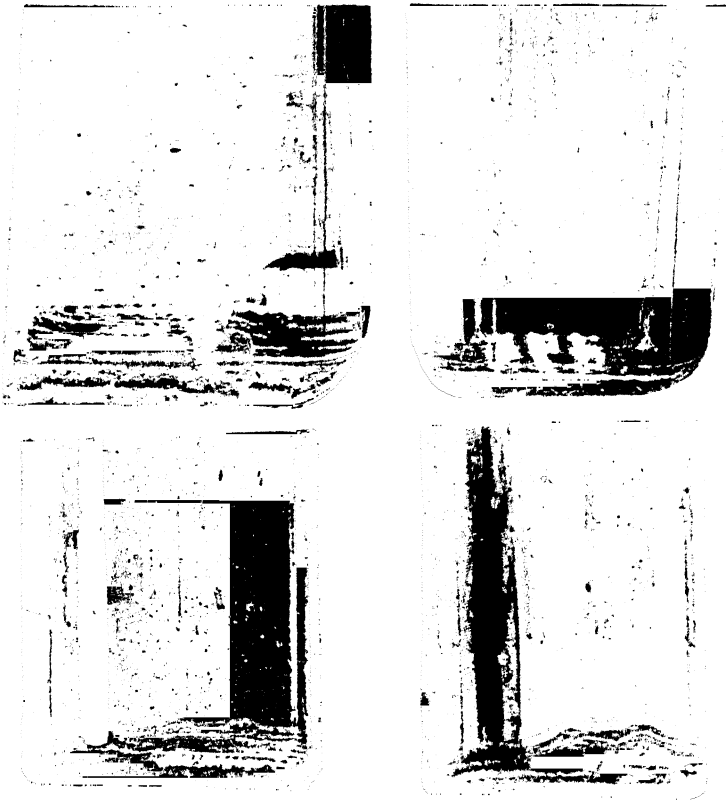


FIG. 1,678.—Undercharged battery. During the process of recharging a battery which had been in an under charged condition long enough for the plates to turn lighter in color, there will be deposited in the bottom of the jar a thin layer of fine white powder as shown

2. The negative plates should be dark gray and the surface of the outside negative plates should be a uniform color.



FIGS. 1,679 to 1,682.—Battery manifestations. If a battery be recharged very slowly so that there is no gassing to cause the electrolyte to circulate, the white deposit (shown in fig. 1,678 will settle down in little ridges as shown in figs. 1,679 and 1,680. This deposit of fine white powder is the indication that the battery had been allowed to stand for some time in an under charged condition before being recharged. If the battery had been allowed to stand in an under charged condition once and then recharged there would be one layer of fine white powder in the bottom of the jar. If the treatment were repeated there would be an additional layer of fine white powder for each recharge which followed a prolonged period of under charging. This is illustrated by the different layers shown in figs. 1,681 and 1,682. When this battery was put into service it was discharged and overdischarged. It was then given a partial charge and discharged again until it would not produce any more current. This was repeated time after time as shown by the number of layers of fine white sediment The battery had a short life and the service was not satisfactory even while it did last. An undercharged battery cannot give satisfactory service.

3. The edges of the positive plates should be very dark brown and should have a fine smooth soft looking texture. Remember that it should be a very dark brown. Some would call it a chocolate color.

Charging and Discharging.—Some of the different ways a battery may be charged and discharged and the effects of each may now be considered. A battery may be:

1. Undercharged;
2. Overcharged too much;
3. Charged properly;
4. Discharged too low.

Undercharged.—If a battery be discharged a normal amount there is no very perceptible change in the color of the plates.

If the battery be allowed to stand in a discharged condition or if it be only partially recharged and allowed to stand in this condition a short time, both the negative and the positive plates will turn slightly lighter in color although the texture of the plates will remain the same for some time.

If the undercharging be continued, that is, if the battery be not given an overcharge, the negative and positive plates will both turn considerably lighter in color in a few months. Carefully noting the colors, a slight change in even a few weeks will be seen. Any tendency of the plates to turn lighter in color is an indication that the battery is being undercharged.

Ques. How should weak cells be treated?

Ans. They should be grouped by themselves and charged as a separate battery, care being taken that the positive strap of one cell, is connected to the negative strap of the adjoining cell and that the charging connections are properly made. If there be not sufficient resistance in the charging rheostat to reduce the current to the proper point, a water resistance should be used.

Overcharged Too Much.—If a battery be not allowed to stand in a discharged or partially discharged condition for more than a week before being recharged and each recharge is carried to completion, there will be no fine white sediment in the bottom of the jar.

The negative plates will always be a dark gray and the positive plates a dark brown. When a battery is being overcharged the sediment thrown down is from the positive plates, and is dark brown and very fine. As it is always necessary to overcharge a battery to some extent, the throwing down of this fine dark brown material from the positive plates is unavoidable. Therefore, a space is provided in the bottom of the jar for this sediment to accumulate. The rate at which it accumulates depends on the amount the cells are gassed.

If a battery be overcharged at a low rate and the overcharge be not continued too long each time, the sediment will accumulate very slowly. When the overcharging is well regulated, the sediment space will hold the accumulation during a period of 5 to 8 years. The sediment space is about 1¾ inches deep and if the overcharging were regulated so that the sediment would be thrown down at the rate of ¼ of an inch a year, the space would hold the accumulation of seven years. It is therefore well to watch the rate at which the sediment accumulates.

If there be no fine positive sediment at all, it is probable that the battery is not being overcharged sufficiently. If the accumulation of fine positive sediment be greater than ¼ inch per year, it indicates that the overcharges are given at a rate which causes too much gassing.

A moderate amount of gassing is hard to describe, but is about the same as that given off from a freshly poured glass of soda water.

Charged Properly.—It may be possible to charge a battery exactly the right amount, but any attempts to do so would require very careful measurements and very close watching, and even then it would be difficult to determine the exact instant the charge was completed. From this it seems necessary to either undercharge or overcharge.

If a battery be undercharged, little or much, the service will be unsatisfactory and the life short. If a battery be overcharged, little or much, the service will in either case be highly satisfactory as long as the battery lasts and the wear on the plates will be in proportion to the amount of overcharging. Therefore, to make it give satisfactory service, a battery must be given the regular overcharge, and to make it give a long life, it must be overcharged as little as possible so long as it is overcharged.

Discharged Too Low.—There is no perceptible wear on a battery during charge as long as the charging current is kept below the gassing point. The wear begins with the overcharge, that is, with the gassing, and the amount of wear is determined by the excessiveness of the gassing.

Likewise there is no perceptible wear during the normal discharge of a battery but if it be overcharged, the life of the battery will be affected. When a battery is discharging, the chemical action which produces the current causes at the same time the formation of lead sulphate in the pores of the plates.

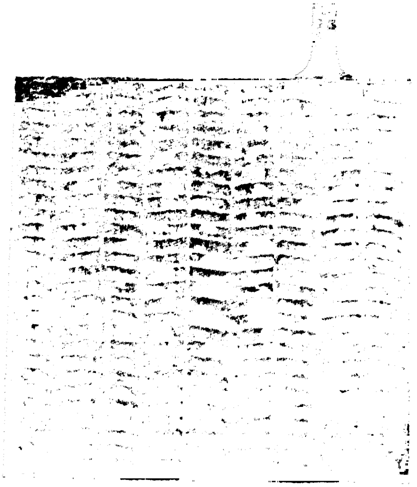


FIG. 1,683.—Battery discharge too low. If the battery had been fully charged just previous to the over discharge, the additional lead sulphate would make room for itself by causing the active material of the negative plates to swell out beyond the surface of the grid as shown in fig. 1,684. A swollen negative plate always indicates that the battery has been over discharged, and also that it was fully charged just previous to the over discharge.

This lead sulphate occupies considerable room, and as the discharge continues the accumulation of lead sulphate fills the pores throughout the plates. At this point the discharge should be stopped as the battery has delivered its normal capacity, which is indicated (when the discharge is at the normal or higher rates) by a tendency of the battery to slow up a little in the production of electricity.

Under average conditions the battery is discharged at less than the normal rate, and there will be no perceptible slowing up in the production of electricity, and it will therefore be necessary to determine the end of the discharge by taking the gravity of the solution as prescribed by the manufacturer.

If a battery be allowed to discharge more than its normal or rated capacity the over discharging will form more lead sulphate in the pores of the plates than they will hold and this additional lead sulphate will make room for itself as explained in fig. 1,683.

Diagnosis of Battery Conditions.—It is not always convenient to watch a battery long enough to see the development of different conditions, but it is often desirable to take a battery after it has been in service for some time and from what is left

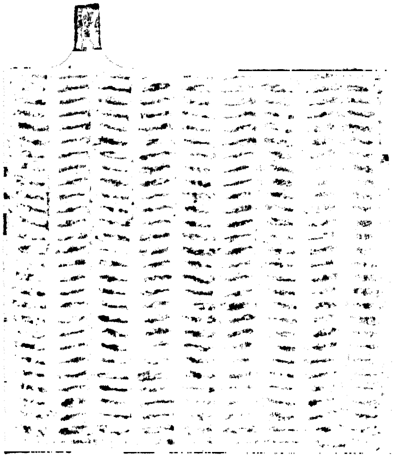


FIG. 1,684.—Battery under charged for long interval. If the battery had been under charged for some time (sufficiently long to allow the plates to become hard) and then over discharged, the additional lead sulphate formed during the over discharge would make room for itself by blowing out the little granular chips of active material, leaving the plate in a pitted condition as shown in fig. 1,683. Again, the additional lead sulphate from over discharging may make room for itself by buckling the plates or cracking the grids. Therefore, a pitted plate, a buckled plate or a cracked grid always indicate prolonged under charging followed by over discharging.

find out the treatment it has received. To do this systematically look for the conditions which will enable you to answer the following questions:

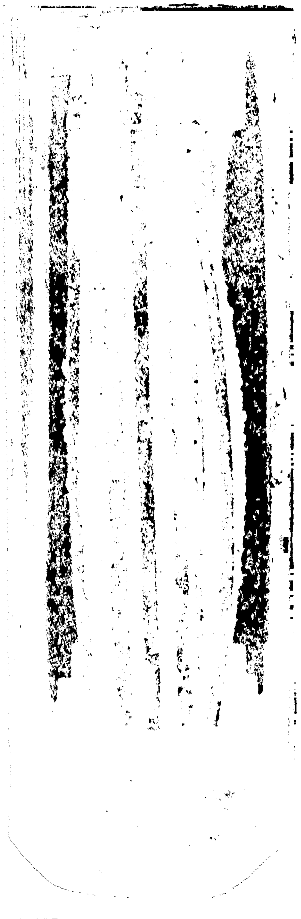
1. Is the electrolyte at the proper height in all of the cells?
2. Are all of the plates and separators in proper position?
3. Are the negative plates light gray, dark gray or dark gray with white powder on the surface?
4. Are the negative plates cracked, buckled, or is the active material falling out in lumps?
5. Are the negative plates blistered?
6. Is the active material of the negative plates swollen out beyond the surface of the grids?
7. Is there a mossy deposit on the tops of the negative plates?
8. How much sediment is there in the bottoms of the jars?
9. Is the sediment dark brown, light brown, gray or white? (If the sediment be deposited in layers of different color, note the amount and color of each, beginning at the bottom. Note also whether the layers be composed of fine or lumpy material.
10. Are the positive plates dark brown or light brown?
11. Are the positive plates cracked, buckled, or is the active material falling out in lumps?

To make application of some of the foregoing, note the condition of the cell shown in fig. 1,685.

Sometimes a single observation will tell a story by itself but more often it is necessary to combine several observations.

Combining the answers to questions 3 and 4 (in fig. 1,385) it will be noted that 3, the negative plates are of a light gray color, that 4, the negative grids are cracked, buckled and the active material is falling out in lumps.

The light color indicates prolonged under charging. That is, some of the sulphate had been allowed to remain in the plates until they became lighter in color and at the same time they became hard. If the plates were accessible while in this light gray condition and the surface scratched with the



point of a knife, it would sound like scratching hard cement. While in this undercharged and hardened condition, the battery was over discharged. The over discharging, that is, the forming of more than a normal amount of sulphate, tended to make the active material expand but as the material was too hard to expand by stretching, it expanded by buckling and cracking the grid.

Further over discharging formed still more sulphate which made room for itself by pushing the material out in small granular lumps as shown sticking out from the surface of the negative plates. Also, some of the lumps have fallen to the bottom of the jar as shown in answer to questions 8 and 9.

To continue operating in the same way, the active material of the negative plates will continue to disintegrate into light gray granular lumps until the entire mass is in the bottom of the jar or lodged in the meshes of the grids. The proper operation of the cell will restore it to practically full capacity and greatly prolong its life. To do this, the battery should be given a full charge at a rate low enough to avoid hard gassing. This may require 75 to 100 hours. Thereafter, charges may be given at the normal rates although the charges should be continued a little longer each time than in the past.

Fig. 1,685.—Storage cell with edge of jar broken away so that condition of interior can be noted. Observe: 1, all of the plates and separators are in proper position; 2, the negative plates are light gray; 3, the negative plates are cracked, buckled and the active material is falling out in lumps; 4, the negative plates are not blistered; 5, the active material of the negative plates is not swollen out beyond the surface of the grids; 6, there is no mossy deposit on the tops of the negative plates; 7, there is about ⅛ of an inch of sediment in the bottom of the jar; 8, the sediment is light gray and lumpy; 9, the positive plates are light brown; 10, one positive plate is slightly cracked, none are buckled and the active material is not falling out in lumps.

When the charge is completed the active material of the negative plates will be restored to a soft spongy lead which will have a dark gray color. Of course the charging will not straighten the buckled plates nor heal the cracks in the grids, but there is enough conductivity left in the grids to carry the current for normal discharge rates.

Referring to questions 8 and 9, the sediment in the bottom of the jar is not great, but there should never be any gray lumpy sediment at all. It indicates prolonged under charging followed by over discharging and although the amount of sediment in the cell is not great, yet the plates are in a condition to throw down more gray lumpy sediment very rapidly under the past method of operation.

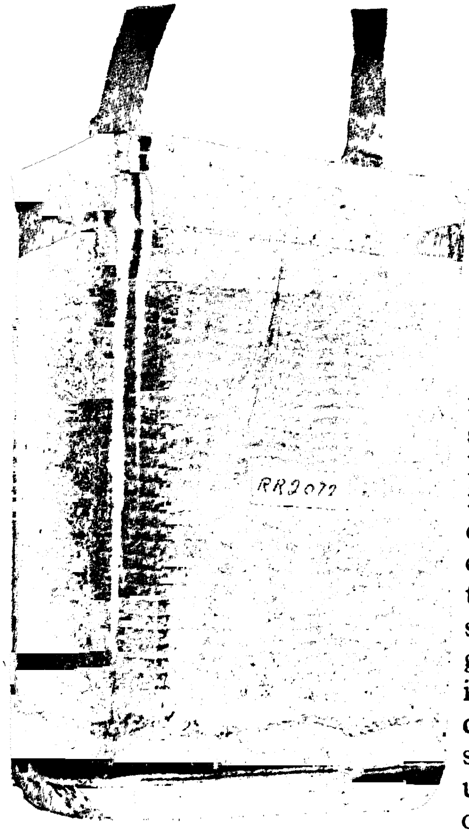


FIG. 1,686.—Second specimen cell for study. *Observe:* the electrolyte is at the proper height; 2, the plates and separators are all in proper position; 3, the negative plates are light gray; 4, the negative plates are not cracked or buckled but the active material is beginning to fall out as shown at the bottom of the plate; 5, the negative plates are not blistered; 6, the active material of the negative plates is swollen out beyond the surface of the grid; 7, there is a mossy deposit on the tops of the negative plates; 8, there is about 1¼ in. of sediment in the bottom of the jar; 9, in the bottom, just on top of the sealing compound, is about ⅛ in. of fine white sediment. On top of this is about 1 in. of fine brown sediment, and on the top about ⅛ in. of light gray lumps; 10, the positive plates are light brown. 11, the positive plates are neither cracked nor buckled but the positive material has begun to fall out in lumps

In questions 10 and 11 it was noted that the positive plates are of a light brown color and that one positive plate is slightly cracked.

The light brown color indicates undercharging and the cracked grid also indicates under charging followed by over discharging. To continue under charging and over discharging would cause the positive plates to turn a little lighter in color. The grids would crack more, probably buckle and the active material would crack and fall out in lumps. Proper operation as already outlined will restore the positive plates to a dark brown color and the cracks in the grids will not interfere with discharging the battery at normal rates.

To make further application of the same questions, note the condition of the cell shown in fig. 1,686.

In reviewing the condition of this cell shown in fig. 1,686, note that it left the factory fully charged, the negative active material being in a soft tough, spongy condition. When in this condition the cell was over discharged, that is, it was fully discharged and after standing a short time was discharged some more and the process repeated until more lead sulphate was formed in the plate than it would hold, thus the extra sulphate made room for itself by swelling out the active material as shown.

Swollen negative plates always show that just previous to the over discharge the negatives had been fully charged, otherwise the over discharge would not have made them swell but buckle and crack.

The cell was later allowed to stand for some time in a fully or partially discharged condition during which time the sulphate inside and on the surface of the plates turned white. This was followed by a recharge which broke up the white sulphate within the plates, but the sulphate on the outside of the plates was thrown off and settled to the bottom of the jar making the thin layer of white sulphate shown just on top of the sealing compound.

The above recharge and subsequent recharges were given at a high rate especially at the finish when the rate should be low. This high rate at the end of charge caused the cells to gas hard over a long period thereby throwing down the deep layer of brown positive sediment. This hard gassing is further shown 7, by the mossy deposit on the tops of the negative plates. This excessive amount of gas coming *up* through the separators in the grooves next to the positive plates washed some of the active material from the positive plates. This upward circulation carried some of the loose positive material up above the plates. It could not settle on the tops of the positive plates because of the upward circulation at that point, but the material went over the tops of the wood separators and settled on the tops of the negative plates where there was no circulation, and as soon as this loose positive material touched the tops of the negative plates, it was converted into spongy negative material as shown. Whenever there is a mossy deposit on the tops of the negative plates, it indicates that at some time the battery had been made to gas hard.

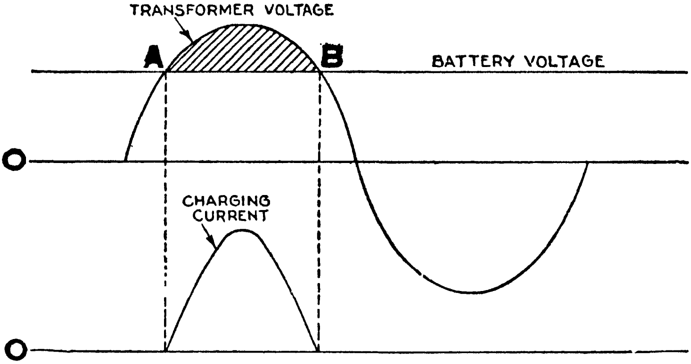


FIG. 1,687.—Diagram illustrating principle on which a storage battery is charged on a Tungar. ***In operation,*** one cycle of half wave rectification is shown. On the upper half of the cycle when the transformer voltage exceeds the battery voltage as at A, the bulb anode becomes positive making the bulb conductive, and the charging current flows through the battery. When the transformer voltage falls below the battery voltage as at B, the bulb is no longer conductive and the charging current ceases on the lower half of the cycle the transformer voltage adds to the battery voltage and since the anode does not become positive, the bulb cannot conduct the current.

In question 11 it was noted that the positive active material has begun to fall out in lumps.

This indicates that the battery was again allowed to stand in an under charged condition which allowed the sulphate to harden and further discharging caused the active material to begin to fall out in lumps. To continue operating the cell as before, that is, to allow it to be under charged, over discharged and recharged at excessive rates, the active material would, in a short time, accumulate in the bottom of the cell. If the cell were given a long charge at a low rate, the negative plates would be restored to a dark gray spongy lead and the positive plates to a dark brown. The cell could afterward be charged at normal rates. Two or three years more service could be expected. With proper care from now on, the cell can be made to give ten times the service it would have given under the previous method of operation.

Capacity.—The capacity of a storage battery *is the product of the current drawn from the battery, multiplied by the number of hours the current flows. The unit in which it is measured is the ampere hour.*

Numerous factors enter into the determination of capacity, principal among which are area of plate surface; quantity, arrangement and porosity of the active material used in the manufacture of the plates; quantity and density (specific gravity) of the electrolyte used; and the porosity of the separators. Temperature also plays an important part, and its effect on capacity is shown by the curve in fig. 1,728.

Charging Characteristics.—The charging characteristics of a battery have very little effect on the ability of a battery to perform a given day's work, provided only that the battery is given enough charge. Violent abuse of a battery by improper charging may at first in no way affect the daily operation; in fact, the necessity for doing a day's work usually results in the battery receiving enough or more than enough, charge to enable it to do the required work, if that be within its capacity; but the charge may be given in such a way as to materially reduce the life of the battery and yet this abuse be entirely unnoticed until after the damage has been done.

NOTE —The S A E. standard hand book provides two methods of rating the capacity of farm lighting batteries, the continuous rating and the intermittent rating ***The continuous rating*** is the capacity in ampere hours of the battery when it is discharged continuously at the eight hour rate. For instance, a battery having a capacity of 100 ampere hours at the eight hour rate will produce a current of 12 5 amperes for a period of eight hours continuously, when discharged to a final voltage of 1 75 volts per cell. ***The intermittent rating*** is the capacity in ampere hours when the battery is discharged intermittently over a period of seventy-two hours to a final voltage of 1 75 volts per cell. Using the intermittent rate of discharge, the capacity is approximately 40 per cent greater than that shown under the eight hour rate.

NOTE.—Lighted cigars, cigarettes, matches, candles or a flame or spark of any kind must never be allowed near the battery while it is charging.

TEST QUESTIONS

1. *Describe a storage cell.*
2. *Name the different types of storage cell, and describe each.*
3. *What is the comparison between the different types?*
4. *How is the electrolyte compared?*
5. *How should the acid and water be mixed?*
6. *What is the density of a fully charged cell?*
7. *How are connections made in charging?*
8. *Describe in great detail the method cf charging.*
9. *What are the charge indications?*
10. *What indicates the completion of a charge?*
11. *What voltage should be used in charging?*
12. *What is "boiling" and what causes it?*
13. *How are cells charged from* 110 *or* 220 *volt circuits?*
14. *Describe the method of charging a new battery.*
15. *What may be said with respect to high charging rates?*
16. *Define ampere hour.*
17. *How may the capacity of a battery be increasea?*
18. *How should a battery room be arranged?*
19. *Give numerous points on care and management.*
20. *How is the positive terminal determined?*
21. *What is buckling?*
22. *Give some causes of sulphation.*
23. *What should be done in case of sulphation?*
24. *What is the cause of lack of capacity?*
25. *How are batteries taken out of commission?*
26. *Give twelve rules for the proper care of batteries.*
27. *What are the indications of proper and improper battery operation?*
28. *Give seven causes of short circuits.*

CHAPTER 44

Battery Charging

Charging.—Before beginning to charge a storage battery, it should be gone over carefully, and any cell that is not up to the standard should be disconnected and put in working order before being replaced.

In general, if the current used in charging be too large, it will waste energy by evolving an excess of heat and gas; if too small, an insulating deposit of white lead sulphate will be formed on the positive plate, thereby preventing the formation of the proper amount of lead peroxide.

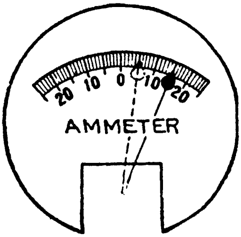


FIG. 1,688.—Method of reading ammeter when the current is unsteady. Owing to the irregularity of the explosion in a hit-and-miss engine, it is almost impossible to maintain a steady reading of the ammeter, as the ammeter hand will swing forward at each impulse of the engine and drop back until the next explosion. In this case, adjust the rheostat so that the ampere reading will be equal to the designated charging rate. If the hand oscillate for instance, between 5 to 15, the current value is ½ (5+15) =10 amperes.

Object of Charging.—*The acid absorbed by the plates during discharge is, during charge, driven from the plates by the charging current and restored to the electrolyte. This is the whole object of charging.*

Dynamo Connections for Charging.—The dynamo cable connections may be made either before or after filling the cells. In making these connections great care should be taken to be sure that *the* ***positive*** *terminal of the battery is connected to the* ***positive*** *lead of the dynamo, and that the* ***negative*** *terminal of the battery is connected to the* ***negative*** *lead of the dynamo.*

In order to insure that the wrong connections are not made accidentally, the dynamo leads should be tested by a pole tester, and the positive and negative poles marked red and black respectively.

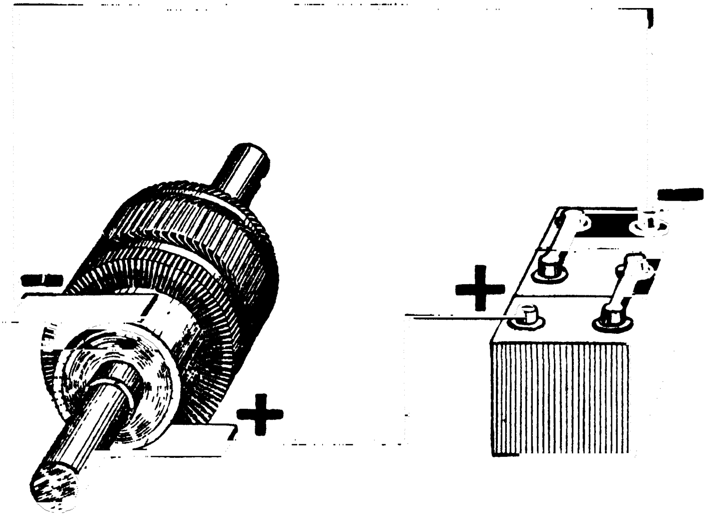


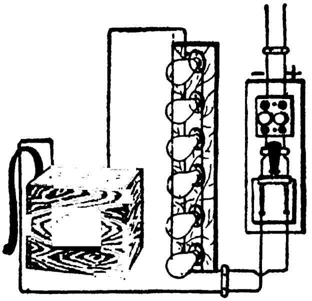
FIG. 1,689.—Dynamo connections for charging. Connect + to + and − to − as shown. ***This diagram*** *shows* ***only*** *the* ***order*** in which dynamo is wired to battery, and not the protective devices, such as switches, fuses, rheostats, etc. which should be included in the circuit.

NOTE.—***To determine the positive wire.*** Without a volt meter, the positive terminal of the charging circuit can be determined by attaching a piece of clean lead to each wire which is to be connected to the battery, and immersing them, without touching each other, in a glass or other insulating vessel containing water to which is added a drop or two of sulphuric acid. After the current has passed through the circuit for a short time, the positive lead will commence to discolor, and, if left long enough, will turn brown. Bubbles will arise from the two terminals immersed, the larger and more frequent ones being from the negative, the smaller ones from the positive.

The polarity of the dynamo wires being determined, they may be joined to the proper terminals by means of suitable clamps or by solder.

Wherever possible the dynamo should be of the direct current, shunt wound, or special compound type, but in cases where only alternating current can be obtained, suitable rectifiers or converters should be used for changing it to direct current.

Cell Connections.—The cells may be connected together ***either in series or parallel, or in parallel-series or series-parallel combinations***, according to the requirements, but in all cases it is best to use the simplest arrangement practicable.



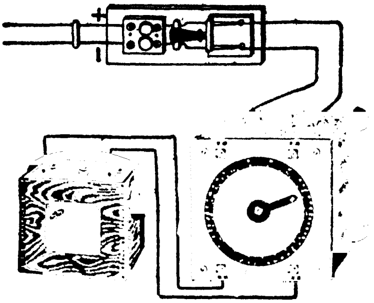


Fig. 1,690.—Diagram illustrating method of charging with lamps in parallel on direct current circuit.

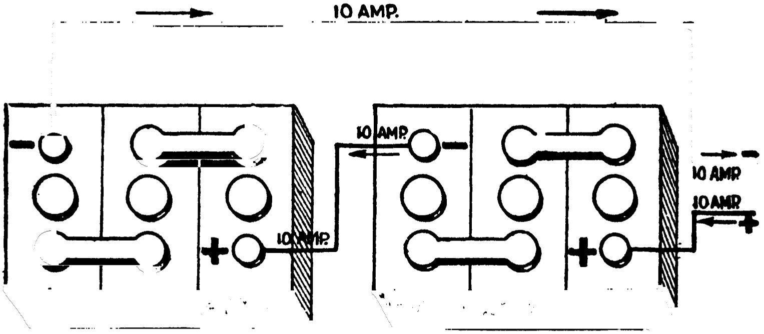
Fig. 1,691.—Diagram illustrating method of charging with rheostat on direct current circuit.

For instance: if the cells employed in an installation requiring 110 volts, have only half the capacity required, and 55 cells give the desired voltage, then the number of cells must be increased to 110, and theoretically the required number of ampere hours at 110 volts may be obtained in one of two ways: 1, by connecting the cells in pairs in parallel and then coupling the pairs together in series, and 2, by arranging the 110 cells in two complete batteries of 55 cells each connected in series, then coupling the two batteries in parallel.

The first method is quite impracticable, however, as the slightest difference between the voltages of the two cells of any pair will result in the one having the greater pressure discharging into the other, thereby causing the entire battery to quickly deteriorate.

Ques. How should a battery be charged for the first time?

Ans. It is essential that the current be allowed to enter at the positive pole at about one-half the usual charging rate prescribed, but after making sure that all necessary conditions have been fulfilled, it is possible to raise the rate to that prescribed by the manufacturers of the battery.



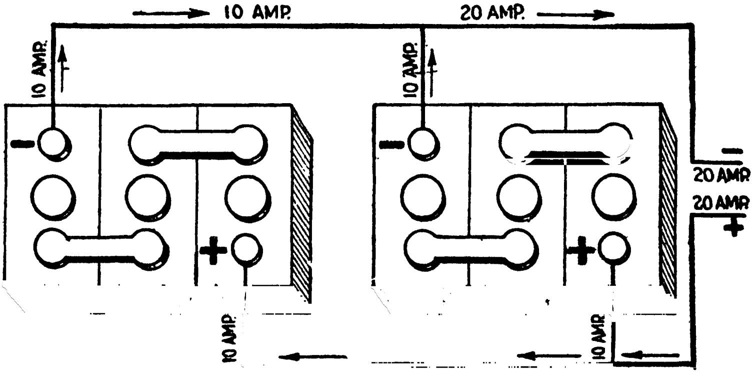


FIG. 1,692.—Connections and current required for charging two batteries *in series*.

FIG. 1,693.—Connections and current required for charging two batteries *in parallel*. The current conditions indicated in the illustration obtain only when the batteries are in the same condition as to charge. Of course the actual current passing through each battery will depend upon the respective battery voltage and charging voltage.

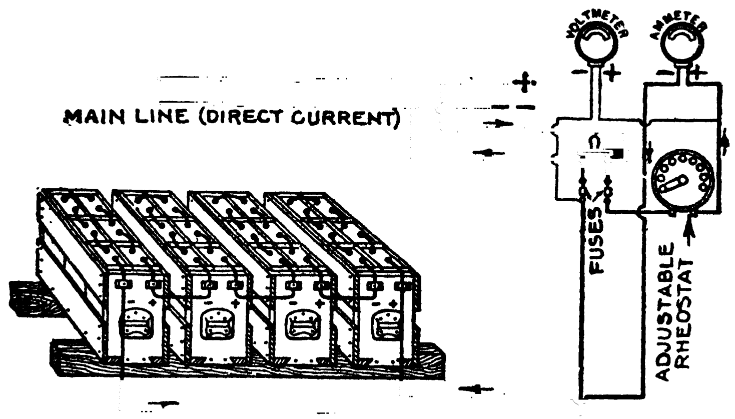


FIG. 1,694.—Charging several batteries, ***rheostatic control.*** *The trays are first connected in series. The current flows from the positive wire of the current supply, into the positive terminal of the first tray (in this case on the right); through the positive and out the negative of each cell and each tray in turn and returns to the current supply from the negative of the last cell. The volt meter is connected between the resistance and the battery in order to show battery voltage.*

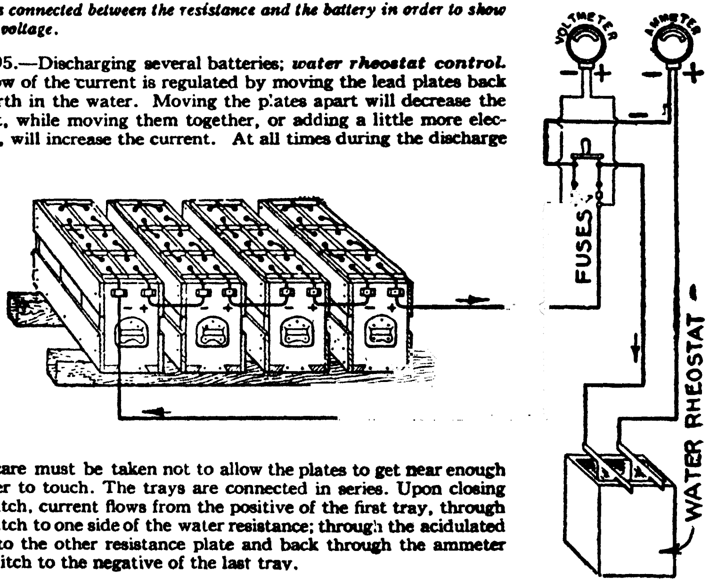


FIG. 1,695.—Discharging several batteries; ***water rheostat control.*** The flow of the current is regulated by moving the lead plates back and forth in the water. Moving the plates apart will decrease the current, while moving them together, or adding a little more electrolyte, will increase the current. At all times during the discharge great care must be taken not to allow the plates to get near enough together to touch. The trays are connected in series. Upon closing the switch, current flows from the positive of the first tray, through the switch to one side of the water resistance; through the acidulated water to the other resistance plate and back through the ammeter and switch to the negative of the last tray.

Ques. What is the usual period for charging a new battery?

Ans. With several of the best known makes of storage battery the prescribed period for the first charge varies between twenty and thirty hours.

Ques. How is the electrolyte affected by the first charge?

Ans A change of specific gravity occurs. The specific gravity should be about 1.150 when the solution is poured into the cells.

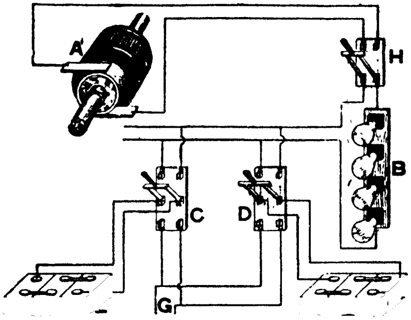
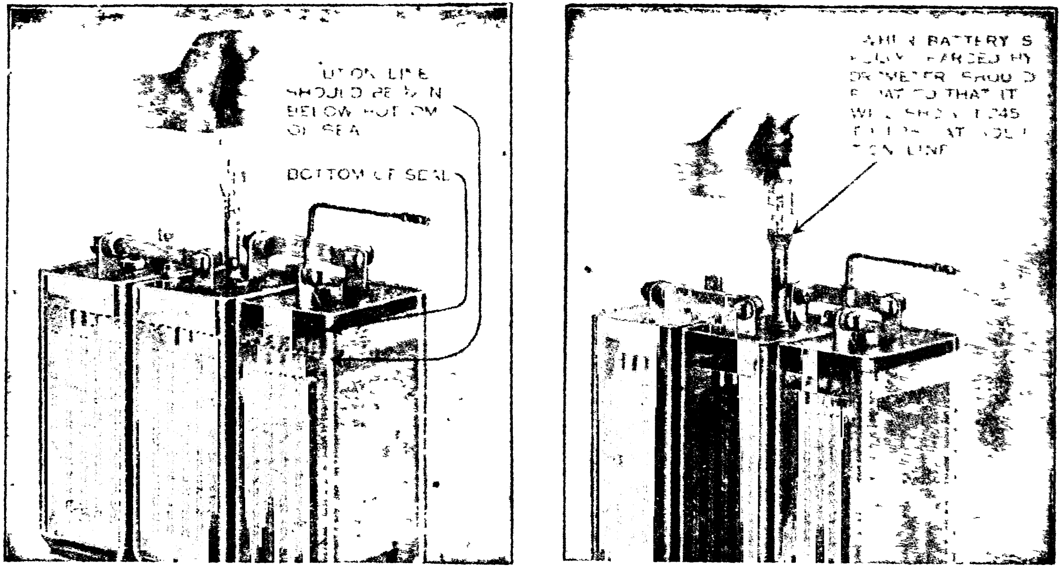


Fig. 1,696.—Diagram illustrating method of charging storage battery of stationary gas engine ignition system; the system is simple to install and will give satisfactory results. Two storage batteries are used, one being charged while the other is operating the sparking coil. Where charging current is available at the point where the batteries are used, the diagram shows the system of connections, which can be easily followed. A, represents the source of charging current and B, the bank of lamps (or other resistance, such as an ordinary rheostat) sufficient to cut down the charging voltage to that required by the battery. C and D, are two double pole double throw knife switches connected at their hinges to two batteries E, each consisting of a group of cells. G, represents the leads to the sparking ing coil terminals. From the diagram, it will readily be seen that by throwing the switches in opposite directions one battery will be charging while the other battery is discharging to the engine, thus giving a constant source of supply, and insuring that the spare battery will be full and ready for service by the time the other is discharged.

At the completion of the first charge, it should, on the same scale be about 1.225. If it be higher than this, water should be added to the solution until the proper figure is reached, if it be lower, dilute sulphuric acid should be added until the hydrometer registers 1.225.



Figs. 1,697 and 1,698.—Method of testing specific gravity of electrolyte with hydrometer; Globe battery. Unscrew vent cap in top of cell. Hold the hydrometer in a vertical position, compress the bulb, and insert the nozzle as far as possible into the cell as shown in fig. 1,697. Gradually lessen the pressure on the bulb until the hydrometer floats about ½ to ¾ of an inch above the bottom. If bulb do not draw up solution, raise hydrometer slightly as the nozzle may be closed by resting on edge of plate. After hydrometer floats raise hydrometer and gently allow bulb to expand, filling with air. The reading of the hydrometer is taken at the top of the solution. The intersections on the scale of the hydrometer at the top of the solution show the correct reading.

NOTE.—***It is important*** that the specific gravity of the cells be taken at regular intervals. By doing this the condition of the battery can be quickly ascertained and if specific gravity be low, battery can be recharged. This will eliminate the possibility of battery becoming over discharged. The specific gravity of a fully charged cell should be from 1.245 to 1.255.

At the first charging of a cell, when the pressure has reached the required limit, the cell should be discharged until the voltage has fallen to about two-thirds normal pressure, when the cell should again be recharged to the normal voltage (2 5 or 2 6 volts).

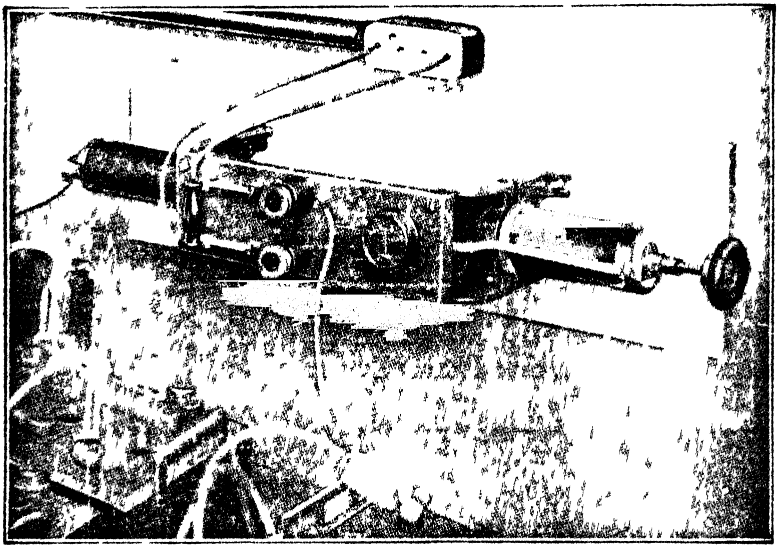


FIG 1,699 —Allen Bradley battery charging panel, designed for controlling the charging current of starting, lighting and ignition batteries when charged from *d c* circuits *In operation* the *d c* feeder is connected to the line switch of the panel Fifteen ampere fuses are furnished in the fuse block, and the batteries to be charged are connected in series with each other One end of the battery line is connected to the fuse block and the other to the graphite disc rheostat The line switch of the panel is then closed, and the hand wheel of the rheostat is slowly turned in a clockwise direction This causes a drop in resistance and the charging current, as indicated by the ammeter on the panel increases The charging current is steplessly advanced to the desired value, and the batteries are then left undisturbed until charged If additional batteries be added to the circuit, or batteries be removed from the circuit, the charging current can be reset to the desired value by turning the hand wheel

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NOTE —***Charging rates.*** In selecting the size of battery to give a certain discharge rate, care should be taken that the dynamo is large enough to charge the battery at a rate not lower than the normal eight hour rate In the case when two halves of a battery are charged in parallel each half taking the normal rate, the dynamo must have a current capacity double that at which each half is to be charged Moreover the dynamo should have capacity to charge the battery occasionally at a higher rate, as this not only improves the condition of the cells, but permits a shorter charging period

The manufacturers of a well known cell of the Plante genus prescribe for the first charge, half rate for four hours, after which the current may be increased to the normal power and continued for twenty hours successively.

Ques. What strength of current should be used in charging a cell?

Ans. It should be in proportion to the ampere hour capacity of the cell.

Thus, as given by several manufacturers, the normal charging rate for a cell of 40 ampere hours should be five amperes, or one-eighth of its ampere hour rating in amperes of charging current.

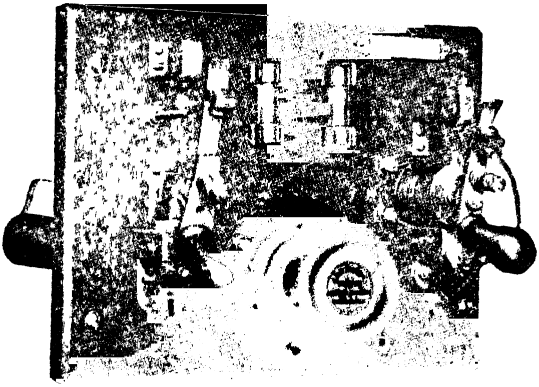


FIG. 1,700.—Allen Bradley unit charging panel for starting, lighting and ignition batteries. ***In operation*** the charging circuit is closed by throwing the charging switch on the left side of the panel, upward. At the same time the underload circuit breaker, on the right side of the panel, must be closed. The circuit is then complete, and the charging current to the batteries flows through both the fuses and the rheostat which is mounted in the center of the panel. o determine the charging current, the switch handle on the left side of the panel, is moved pward about an inch. This action automatically connects the ammeter, at the top of the switch board into the charging circuit. While holding the switch in this position, the battery man can adjust the charging current with the rheostat hand wheel, to any desired value. As soon as the correct value of charging current is obtained, the battery man takes his hand from the charging switch, and it automatically drops back to the normal position which removes the ammeter from the circuit. In other words, the ammeter is not connected into the charging circuit unless the battery man purposely lifts the charging switch handle upward, and holds it there. With this arrangement one ammeter will serve a number of unit charging panels, since it can be connected into any circuit by simply lifting the handle of the proper charging switch.

Ques. What should be the voltage of the charging current before closing the charging circuit?

Ans. The voltage should be at least ten per cent. higher than the normal voltage of the battery when charged.

Ques. What indicates the completion of a charge?

Ans. When a cell is fully charged the electrolyte apparently boils and gives off gas freely. The completion of a charge may be determined by the volt meter, which will show whether the normal pressure has been attained.

Ques. How should the voltage be regulated during the first charge?

Ans. It should be allowed to rise somewhat above the point of normal pressure.

Ques. How often should a battery be charged?

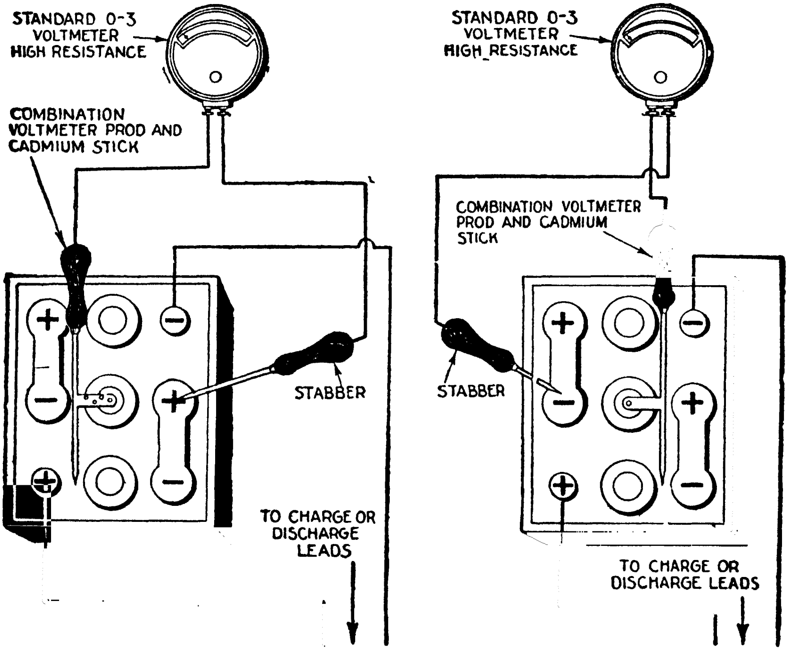
Ans. At least once in two weeks, even if the use be only slight in proportion to the output capacity.

In charging a storage battery, it is essential to remember the fact that the normal charging rate is in proportion to the voltage of the battery.

Thus, a 100 ampere hour battery, charged from a 110 volt circuit at the rate of ten amperes per hour, would require ten hours to charge, and would consume in that time an amount of electrical energy represented by the product of 110 (voltage) by 10 (amperes) which would give 1,100 watts, or 1.1 *kw*.

Ques. If in charging a battery, one or more of the cells do not boil at the completion of the charge, or fail to show the proper voltage, what should be done?

Ans. The charging must be continued until the cadmium test shows the required voltage, but if the prolonging of the charge be liable to damage the plates in the other cells, the defective cell or cells should be cut out of circuit when the battery discharges and then placed in circuit again when the battery is recharged. If the desired result cannot be attained by this



Figs 1,701 and 1,702 —Method of making a cadmium test Fig 1,701, test of positive plates fig 1,702 test of negative plates When a strip or rod of cadmium is placed across the top of the plates in a cell and properly insulated from them, there will be a difference in pressure between the positive plates and the cadmium and between the negative plates and the cadmium, the difference between these two readings being equal to the voltage of the cell In a normal cell there is a well defined relation between these readings, both on charge and discharge, and any appreciable variation is an indication of irregularity of action of either the positive or negative plates, according to which reading shows the variation The positive cadmium reading will normally range from about 2 15 volts down to 1 95 volts during a discharge at the eight hour rate, and from about 2 20 volts up to about 2 50 volts during a charge The range for the negative cadmium reading is from about 15 volt at the beginning of the discharge to about 30 volt at the end During charge the range is from about 15 volt to – 20 volt (20 volt reversed polarity) with new or nearly new plates, as the plates age, the reading at the end of charge diminishes until it falls to about zero volts method, the plates which require additional charging may be charged in a separate cell.

Ques. How is the cadmium test made?

Ans. A plate of cadmium is mounted in a hard rubber frame and immersed in the electrolyte.

The test consists in taking voltage readings between the cadmium plate and the positive or negative plates of the cell. During charge the cadmium plate reads negative to the negative plate, until the cell is about full, when the reading should be zero; the charge should be continued until the cadmium reads .2 volt positive to the negative while charging at the normal rate.

FIG. 1,703.—Weidenhoff cadmium test meter *Designed* to give the open voltage of a cell and the reading positive and negative plates to cadmium

Ques. Name some portable instruments that should be provided for testing batteries.

Ans. 1, a hydrometer syringe (specific gravity tester); 2, an acid testing set (can be used instead of the syringe); 3, a low reading volt meter; 4, suitable prods, and 5, a thermometer.

NOTE.—***To make a "cadmium stick."*** Take a cadmium rod about 6 ins. long and about ¼ in in diameter Insulate rod with rubber tube perforated with a number of holes 1/16 in. in diameter Solder to end of cadmium rod a copper wire long enough to reach all cells and attach handle

Ques. What precaution should be taken in charging a battery?

Ans. Care should be taken not to have a naked flame anywhere in its vicinity.

To either charge or discharge a battery at too rapid a rate involves the generation of heat. Thus, while this is not liable to result in a flame under usual conditions, the battery may take fire, if it be improperly connected or improperly used.

Ques. What is the effect of varying the charging current?

Ans. In charging a storage cell, particularly for the first time, a weaker current than that specified may be used with the same result, provided the prescribed duration of the charge be proportionally lengthened. The battery may also be occasionally charged beyond the prescribed voltage, ten or twenty

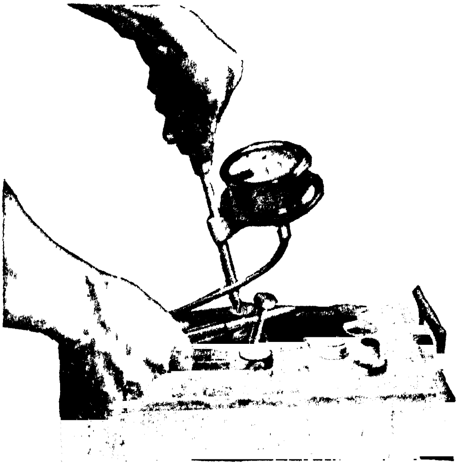


Fig. 1,704.—Weidenhoff cell tester; view showing operator taking open voltage cell reading. It is useful in checking the voltage of batteries while on the charging line.

per cent. overcharge causing no injury, although if frequently repeated, it shortens the life of the battery.

Charge Indications.—The state of the charge is not only indicated by the density of the electrolyte and the voltage of the cell, but also by the *color of the plates*, which is considered by many authorities as one of the best tests for ascertaining the condition of a battery.

Ques. What are the colors of the plates?

Ans. In the case of formed plates, and before the first charging, the positives are of a dark brown color with whitish or reddish gray spots, and the negatives are of a yellowish gray.

The whitish or reddish gray spots on the positive plates are small particles of lead sulphate which have not been reduced to lead peroxide during the process of forming, and represent *imperfect sulphation*.

As a general rule, the first charging should be carried on until these spots completely disappear. After this the positive plates should be of a dark brown or chocolate color at the end of the discharge, and of a wet slate or nearly black color when fully charged. A very small discharge is sufficient, however, to change them from black to the dark brown or chocolate color.

If the battery has been discharged to a pressure lower than 1.8 volts, the white sulphate deposits will reappear, turning the dark red color to a grayish tint in patches or all over the face of the plate, or in the form of scales of a venetian red color.

The formation of these scales while charging indicates that the maximum charging current is too large and should be reduced until the scales or white deposits fall off or disappear, after which the current can be increased again.

During charging, the yellowish gray color of the negatives changes to a pale slate color which grows slightly darker at the completion of the charge. The color of the negatives always remains, however, much lighter than that of the positives.

Ques. How are the best results obtained in charging?

Ans. The rate of charge should be normal, except in cases of emergency.

At such a rate, unless the constant voltage method be employed, the cell may be considered full when the volt meter reads 2.5 volts during charge. The electrolyte should be kept at uniform density throughout the cell; when water is added, because of evaporation, it should be added by means of a funnel reaching to the bottom of the cell. Care should be taken never to add acid after evaporation; otherwise the electrolyte will be too heavy. Hydrometer readings should be taken regularly; the reading is an excellent indication of the amount of charge in the battery. Hydrometer readings are useless, however, unless the precaution be taken to keep the electrolyte of uniform density.

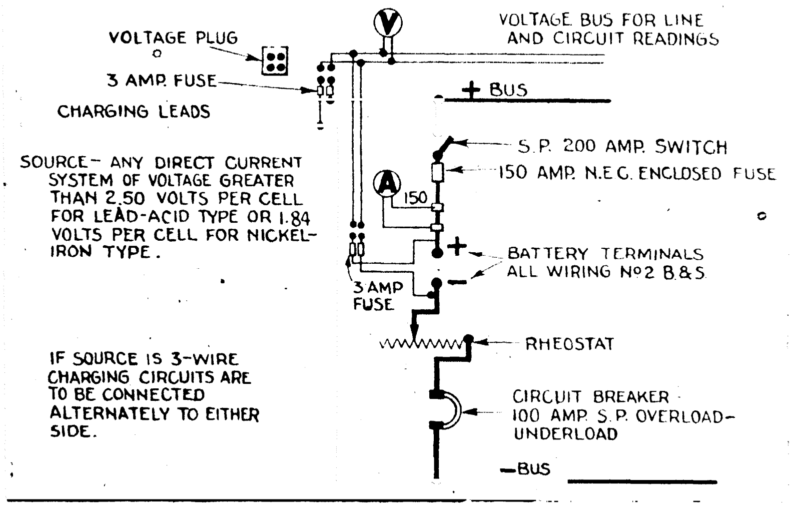

V
VOLTAGE BUS FOR LINE AND CIRCUIT READINGS
VOLTAGE PLUG
3 AMP. FUSE
CHARGING LEADS
+ BUS
S.P. 200 AMP. SWITCH
150 AMP. N.E.C. ENCLOSED FUSE
SOURCE – ANY DIRECT CURRENT SYSTEM OF VOLTAGE GREATER THAN 2.50 VOLTS PER CELL FOR LEAD-ACID TYPE OR 1.84 VOLTS PER CELL FOR NICKEL-IRON TYPE.
A
150
+
BATTERY TERMINALS
ALL WIRING No 2 B.&S.
–
3 AMP FUSE
RHEOSTAT
IF SOURCE IS 3-WIRE CHARGING CIRCUITS ARE TO BE CONNECTED ALTERNATELY TO EITHER SIDE.
CIRCUIT BREAKER 100 AMP. S.P. OVERLOAD-UNDERLOAD
—BUS

Fig. 1,705.—Circuit for ***constant current*** method of charging as suggested by the Bureau of Standards.

Ques. What voltage should be used in charging?

Ans. At the beginning of the charge the voltage should be about 5 per cent. higher than the normal voltage of the battery, unless the latter has been over discharged, in which case the difference of pressure should not exceed 2 per cent., otherwise the current might be too large.

Ques. In what two ways may batteries be charged?

Ans. They may be charged either at constant current or at constant voltage.

Although the latter method is considered the better one by many authorities, it is a fact, nevertheless, that if the charging current be normal at the beginning of the charge, and no means be provided for keeping it constant, it will diminish as the charging progresses, thereby greatly increasing the length of the time required for charging, and resulting in serious injury to the plates.

Ques. How may the charging current be kept constant?

Ans. Its voltage should be gradually increased, first to about 10 or 15 per cent. above the voltage of the battery, and kept at that point nearly to the end of the charge, where in consequence of the rapid rise of pressure in the battery it might become necessary to increase the voltage of the current to 30 or 40 per cent. above the normal of the battery.

Ques. What tests should be made while charging?

Ans. Occasional voltage and cadmium readings of each cell should be taken for the purpose of ascertaining their condition and the behavior of the separate plates.

Ques. What tests should be made after charging?

NOTE —***Constant voltage method of charging.*** In this method ***the voltage is maintained at a constant fixed value per cell*** The value of the initial, or starting current, of a completely discharged battery, when first put on charge, is much in excess of that of the normal rate During the charge, as the voltage of the battery gradually rises, the back pressure or battery voltage causes the current to drop to a value much below that of the normal rate and at the end of the charge is usually below that of the finishing rate of the constant current system The average value of the current is adjusted so as to be about equal to that of the normal rate. In practice the pressure at the bus bars may range from 2 5 to 2 75 volts per cell.

Ans. Each cell should be tested with a low reading volt meter and hydrometer about once a week. If any cell read low, it should be cut out and examined to see if any material has been introduced which would cause a short circuit. If this trouble do not exist, the cell should be given an independent charge.

The formation of these scales during charging indicates that the maximum charging current is too large and should be reduced until the scales or white deposits diminish or disappear, after which the current can be increased again.

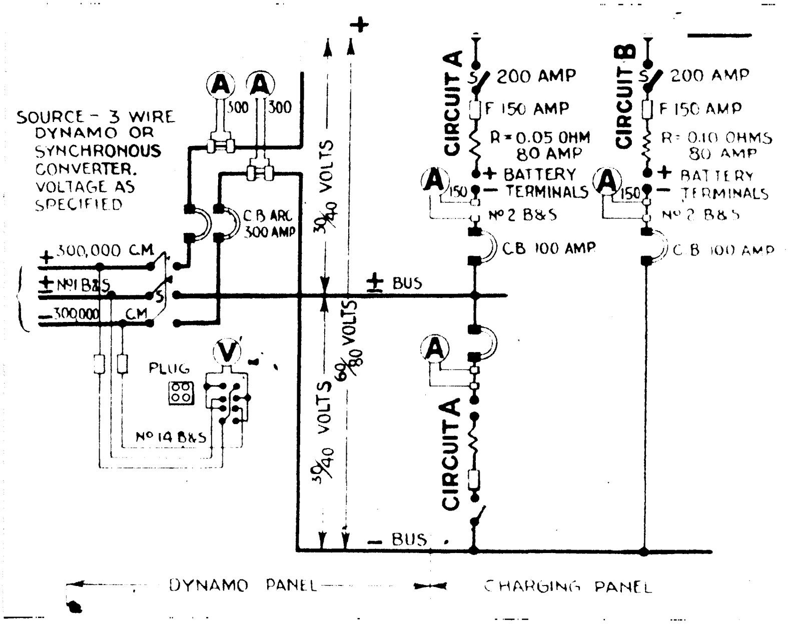
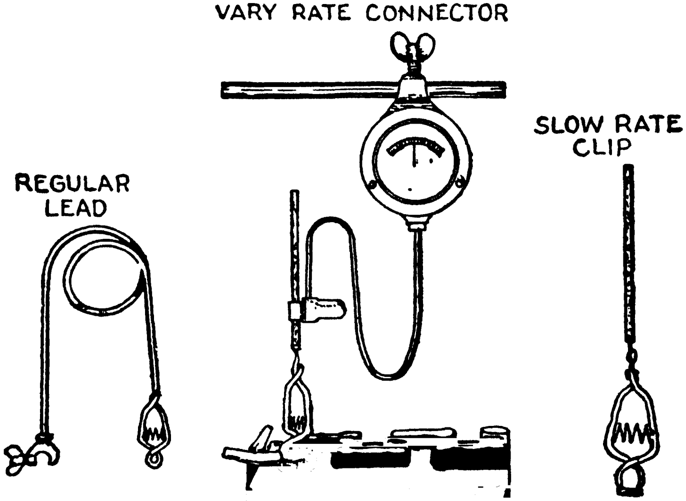


FIG. 1,706.—Circuit for modified constant pressure method of charging as suggested by the Bureau of Standards.

Ques. Describe the behavior of the electrolyte during discharge.

Ans. There is a definite change in the density of the electrolyte for a given amount of discharge.

The density of the electrolyte is, therefore, one of the best indications of the state of charge, provided, of course, no internal discharge due to local action take place. If, when the cell is charged, it show a density of 1.200, and when discharged 1.130, the difference .07 represents the total charge. If at any time the density be 1.165, then just one half the amount of capacity has been taken from the cell.



FIGS. 1,707 to 1,709.—H. B. battery charging connections. Fig. 1,707, regular lead; fig. 1,708, vary rate connector; fig. 1,709, slow rate clip.

It is necessary to stir the electrolyte well, in order for these observations to be reliable.

If the discharge has taken place at a high rate, the cell must stand for an hour or more before the electrolyte will completely diffuse so that the density readings are correct.

Ques. Define the term "boiling."

Ans. Boiling means the rapid evolution of gas when a cell is nearly charged.

Ques. What causes boiling?

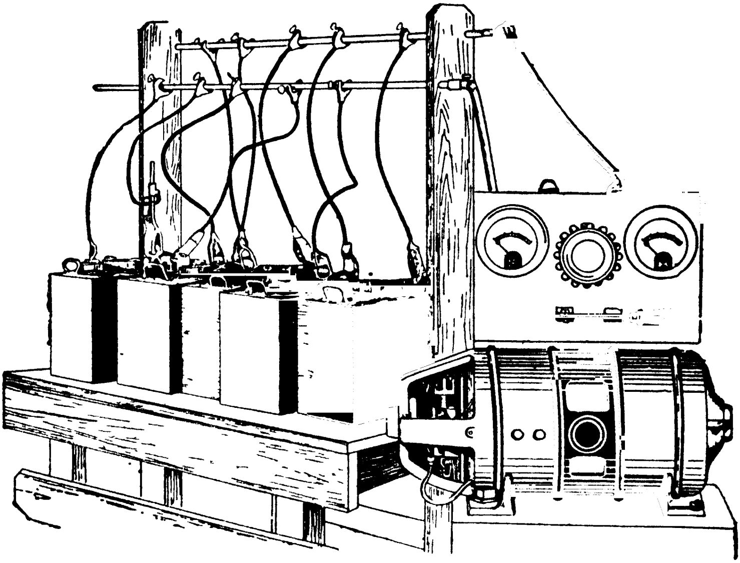


FIG. 1,710.—Battery charging bench with bus bars and connections to motor dynamo charging unit. The charging unit consists of a combination *d.c.* or *a.c.* motor and dynamo working on the same shaft. The dynamo is wound to supply current at a suitable voltage for the service required and the *d.c.* or *a c.* motor for the voltage of the supply current. This avoids the considerable loss due to placing resistance in the form of rheostat or lamp bank in the circuit to obtain the considerable reduction of pressure required when charging for lighting circuits.

Ans. The amount of sulphate to be converted into peroxide becomes less and less as the charge progresses and the plates therefore become virtually smaller, so that the current becomes too large for the work demanded of it. The result is, that part of the current not actually used in the formation of peroxide decomposes the electrolyte into its constituent elements.

Ques. What may be said of charging a battery as quickly as possible?

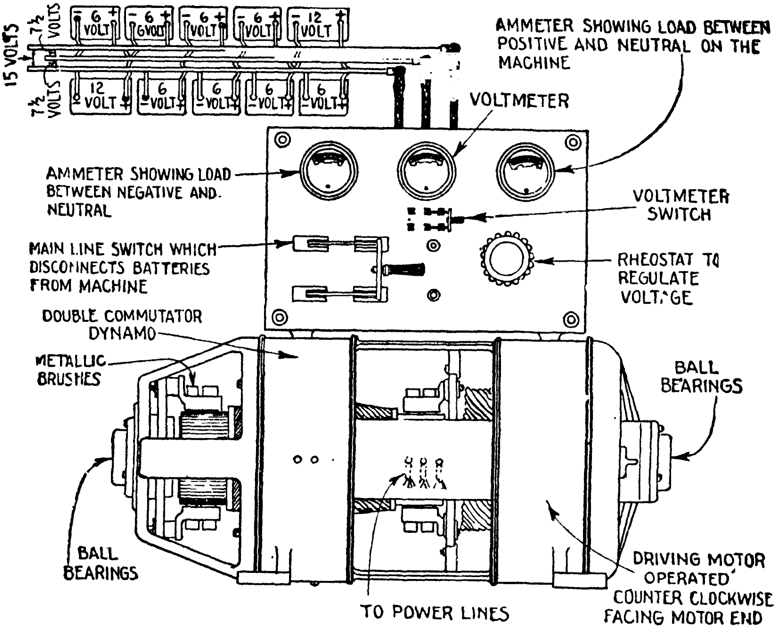

15 VOLTS
7½ VOLTS
6 VOLT
6 VOLT
6 VOLT
6 VOLT
12 VOLT
7½ VOLTS
12 VOLT
6 VOLT
6 VOLT
6 VOLT
6 VOLT
AMMETER SHOWING LOAD BETWEEN POSITIVE AND NEUTRAL ON THE MACHINE
VOLTMETER
AMMETER SHOWING LOAD BETWEEN NEGATIVE AND NEUTRAL
VOLTMETER SWITCH
MAIN LINE SWITCH WHICH DISCONNECTS BATTERIES FROM MACHINE
RHEOSTAT TO REGULATE VOLTAGE
DOUBLE COMMUTATOR DYNAMO
METALLIC BRUSHES
BALL BEARINGS
BALL BEARINGS
DRIVING MOTOR OPERATED COUNTER CLOCKWISE FACING MOTOR END
TO POWER LINES

FIG. 1,711.—Hobart motor dynamo charging unit for three wire circuit with attached instrument panel. The double throw volt meter switch in position shown connects volt meter with neutral and positive bus bars; when thrown to left, it connects with neutral and negative bars.

Ans. As a general rule, such a procedure should not be adopted unless the battery be thoroughly discharged.

Ques. What precaution should be taken?

Ans. The danger to be avoided in rapidly charging a cell is its tendency to heat.

Ques. What apparatus is necessary in charging a battery?

Ans. The battery may be charged from direct current mains having the proper voltage. A current as near uniform as possible is required, and existing conditions must be met in each separate case. Sometimes a motor dynamo set with a regulating switch board is used. Such an apparatus consists of a dynamo, driven direct from the shaft of a motor, which, in turn, is energized by current from the line circuit.

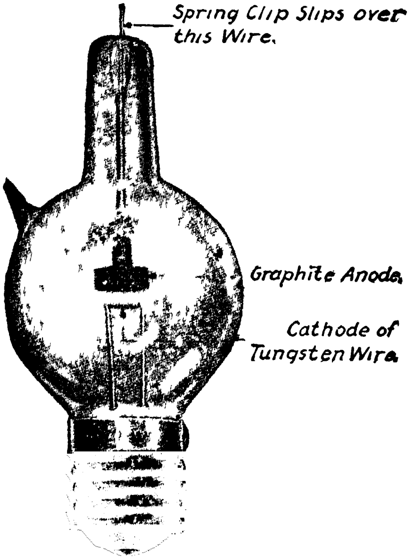


FIG 1,712 —General Electric half wave Tungar bulb of Tungar battery charger The name Tungar applies to a hot cathode gas filled rectifier and has no particular significance ***Principle:*** ***a vacuum tube containing a hot and cold electrode acts as a rectifier***, that is it changes alternating current into direct current In the Tungar bulb there is argon, an inert gas, at low pressure, which is ionized by the electrons emitted from the incandescent filament This ionized gas acts as the principal current carrier, with the result that the bulb operates with a very low voltage drop (of 3 8 volts) and is capable of passing a current of several amperes, the current limit depending on the design and size of the tube ***In construction,*** the cathode (lower cathode) consists of a filament of small tungsten wire coiled into a closely wound spiral, and a graphite anode (upper electrode) of relatively large cross section

With a direct current on the line, a dynamo may be used; but with an alternating current, an induction motor is required. The speed of the motor is governed by a rheostat, and the output of the dynamo is thus regulated as desired.

Charging Through the Night.—If an automobile, after a late evening run, is to be used in the morning, the battery may be charged during the night without an attendant being present; but in doing this great care must be taken not to excessively over charge.

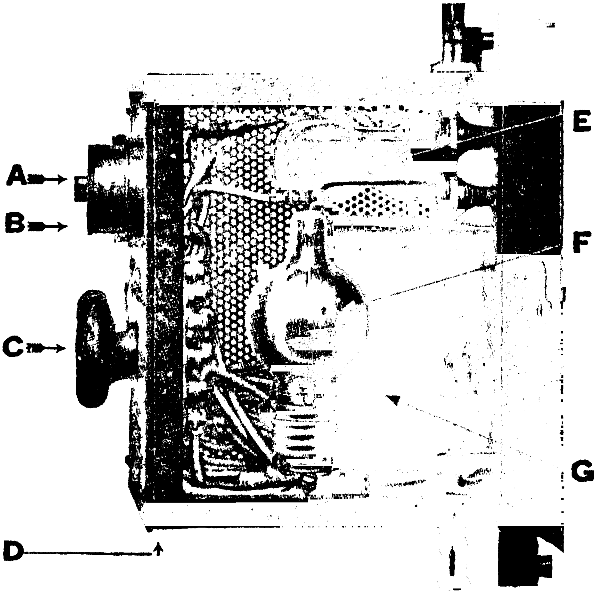


FIG. 1,713.—General Electric ten battery Tungar charger. ***The parts are:*** **A**, triple pole snap switch which controls both *a c.* lines and one *d c.* line; **B**, *d c.* ammeter, **C**, fifteen point dial switch giving charging current adjustment in small steps, **D**, steel casing; **E**, reactance coil, or electrical governor of the charging circuit; **F**, Tungar bulb which changes the alternating current into direct current, **G**, auto transformer.

A careful estimate of the amount of current required should be made and the rate of charge based on this estimate.

If, say, 72 ampere hours be required to recharge, and the time available be nine hours, the average rate of charge must be 8 amperes.

If charging from a 110-volt circuit, the rate at the start should be about 10 amperes; if from a 500 volt circuit, about 9 amperes; as, in charging from a source with constant voltage, such as a lighting or trolley circuit, the rate into the battery will fall as the charge progresses. This also

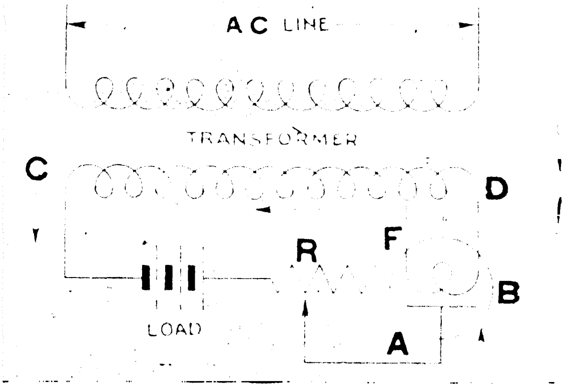
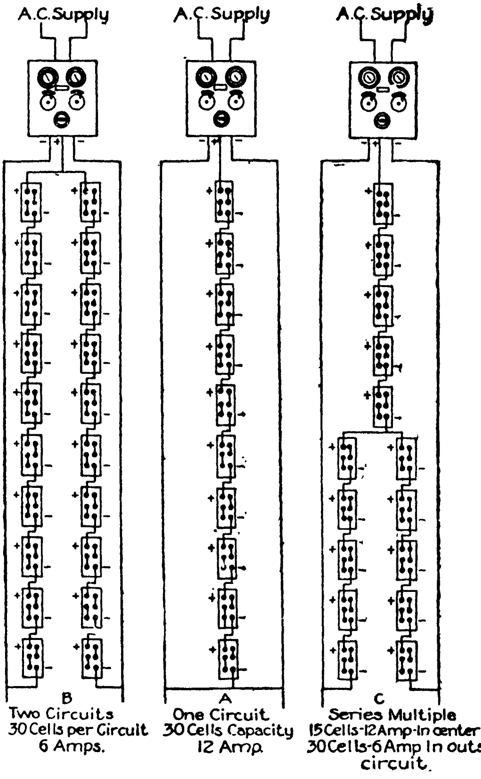


FIG. 1,714 —Diagram showing connections of General Electric Tungar half wave rectifier in its simplest form *The parts shown are:* **A**, anode, **B**, Tungar bulb, **CD**, secondary of transformer; **F**, filament cathode, **R**, rheostat. Assuming an instant when the side **C**, of the alternating current supply is positive, the current follows the direction of the arrows through the load, rheostat, bulb and back to the opposite side of the *a c.* line. A certain amount of the *a c* of course goes to excite the filament, the amount depending on the capacity of the tube In actually designing the rectifier outfits the rheostat is omitted and the regulation entirely obtained by means of a compensator, with which is combined the filament transformer, and a reactance When the *a c* supply reverses and the side **D**, becomes positive the current is prevented flowing for the reason before mentioned In other words, the current is permitted to flow from the anode to the cathode or against the flow of emitted electrons from the cathode, but it cannot flow from the cathode to the anode with the flow of electrons.

NOTE —***Tungar operation.*** This rectifier is operated by means of a snap switch in the upper left-hand corner (see **A**, fig 1,713) and a regulating switch in the center (**C**, fig. 1,713). Before starting the apparatus, the regulating switch should be in the "low" position. The Tungar is now ready to operate Turn the snap switch to the right to the "on" position, and the bulb will light. Then turn the regulating switch slowly to the right; as soon as the batteries commence to charge, the needle on the ammeter will indicate the charging current. This current may be adjusted to whatever value is desired within the limits of the Tungar. The normal charging rate is six amperes, but a current of as high as seven amperes may be obtained without greatly reducing the life of the bulb Higher charging rates reduce its life to a considerable extent Lower rates than normal (six amperes) will increase the life of the bulb. Turn the snap switch to the "off" position when the charging of one battery or of all the batteries is completed, or when it is desired to add more batteries to the charge. The Tungar should be operated only by the snap switch and not by any other external switch in either line or battery circuits. When the snap switch is turned, the batteries will be disconnected from the supply line, and then they may be handled without danger of shock. Immediately after turning the snap switch move the regulating handle back to the "low" position. This prevents any damage to the bulb from the dial switch being in an improper position for the number of batteries next charged.

applies if the charging be done from a mercury arc rectifier without attendance.



FIGS. 1,715 to 1,717.—Connections for batteries and Tungar charger. Fig. 1,715, two circuits 30 cells per circuit 6 amperes; fig. 1,716, one circuit, 30 cells capacity, 12 amperes; fig. 1,717, series parallel, 15 cells at 12 amperes in center circuit, 30 cells at 6 amperes in outside circuit.

NOTE.—*A Tungar charger* will operate successfully at as low as one or two amperes, and up to seven amperes on either circuit, and up to 12 or 14 amperes on both circuits. If only one battery be operated at one time, on one circuit, it may be necessary to use an external resistance to obtain as low as one or two amperes.

NOTE.—*A Tungar* will stop charging if there be an interruption of the supply voltage, but damage cannot result as the battery will not discharge through the outfit, charging will immediately commence upon resumption of the supply voltage.

Ques. What precautions should be taken in charging a battery out of an automobile?

Ans. When a battery is being overhauled, the cells must be connected together in series and to the charging source in relatively the same manner as if they were in the vehicle; that is, the positive (+) terminal of one group of cells must be connected to the negative (−) terminal of the next group, and the two free terminals, one positive and the other negative, must be connected repectively to the positive and negative terminals of the charging circuit, but not until all of the groups have been connected in series.

If the cells be provided with formed plates and not charged, the jars should be filled with the proper electrolyte, and then charged for at least 10 hours steady, or until they boil, then they may be discharged.

In the case of unformed plates, the charging should be from 30 to 40 hours, until the cells boil, and the plates assume their proper color.

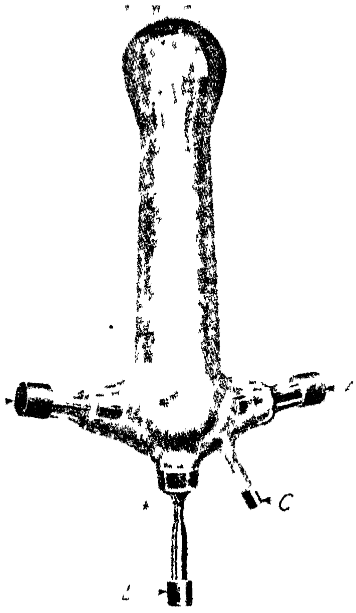


FIG 1,718 —General Electric single phase mercury arc tube *It consists of* an exhausted glass vessel containing two anodes **AA**, one cathode **B**, a starting anode **C**, and a small quantity of mercury

Ques. How are small cells easily charged from 110 or 220 volt circuits?

Ans. This may be conveniently done by inserting in one of

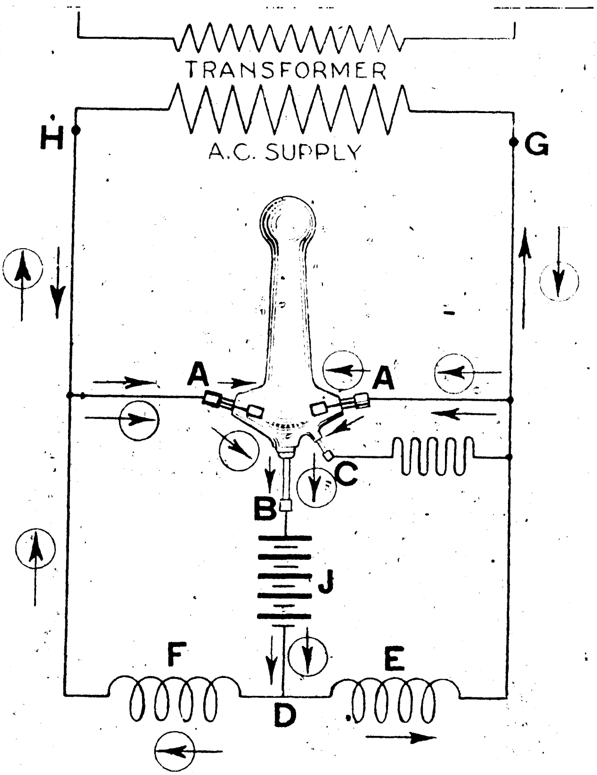


FIG. 1,719 —Connections of General Electric mercury arc rectifier At the instant the terminal H, of the supply transformer is positive, the anode A, is then positive, and the current can flow between A and B Following the direction of the arrow still further, the current passes through the battery J, through one-half of the main reactance coil E, and back to the negative terminal G, of the transformer When the impressed voltage falls below a value sufficient to maintain the arc against the reverse voltage of the arc and load, the reactance E, which heretofore has been charging, now discharges, the discharge current being in the same direction as formerly. This serves to maintain the arc in the rectifier tube until the voltage of the supply has passed through zero, reversed, and built up such a value as to cause the anode A, to have a sufficiently positive value to start the arc between it and the cathode B. The discharge circuit of the reactance coil E, is now through the arc A'B, instead of through its former circuit Consequently the arc A'B, is now supplied with current, partly from the transformer, and partly from the reactance coil E The new circuit from the transformer is indicated by the arrows enclosed in circles.

the charging leads an incandescent lamp or lamp tank which will pass the required quantity of current.

If the current required be as large as 10 amperes, a suitable resistance or 10 lamps in parallel, each passing one ampere, may be used. Great care should be taken to see that the battery is connected properly.

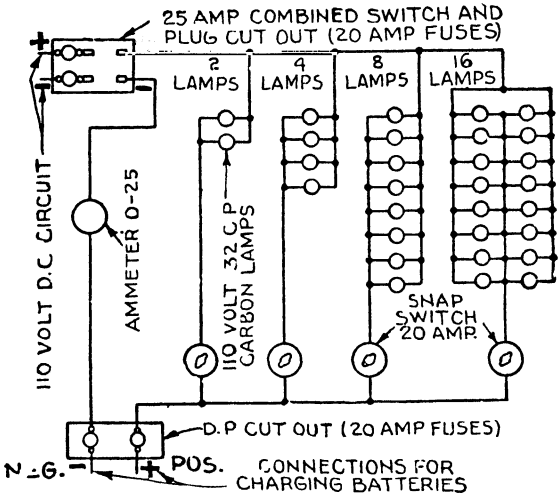

25 AMP COMBINED SWITCH AND PLUG CUT OUT (20 AMP FUSES)
+
−
2 LAMPS
4 LAMPS
8 LAMPS
16 LAMPS
110 VOLT D.C. CIRCUIT
AMMETER 0-25
110 VOLT 32 C.P. CARBON LAMPS
SNAP SWITCH 20 AMP.
D.P CUT OUT (20 AMP FUSES)
NEG.
POS.
CONNECTIONS FOR CHARGING BATTERIES

FIG. 1,720.—Wiring diagram for charging one to twelve 6-volt batteries from 110 volt bus. With this equipment regulation of the current through various numbers of batteries is obtained by means of the switches. Instead of lamps, *resistance units*, of approximately 35 ohms resistance and 3.3 amperes capacity each may be used. This equipment will occupy less space than the lamps and serve the same purpose, each resistance unit replacing two lamps. Instead of either a lamp resistance or unit resistance panel, a special form of *rheostat* may be used. However lamps are advisable where the light for some may serve for illumination, otherwise the energy spent in heating the resistance is a total loss. Accordingly, where lighting is not required, avoid resistance as much as possible by connecting the batteries so that their combined voltage will almost equal that of the source.

Trickle Charge Method.—When a number of batteries are to be held in wet storage, the most satisfactory results can be obtained by charging continuously at a very low rate, which is so low that gassing is avoided and yet gives enough charge to maintain the batteries in good condition. This charge is termed a trickle charge, and in many cases will be found more convenient to arrange for than the periodic charge. It has the added advantage of keeping the batteries in condition for putting into use at any time on short notice.

In giving batteries a trickle charge:

1. Give a charge until *all* the cells are gassing.

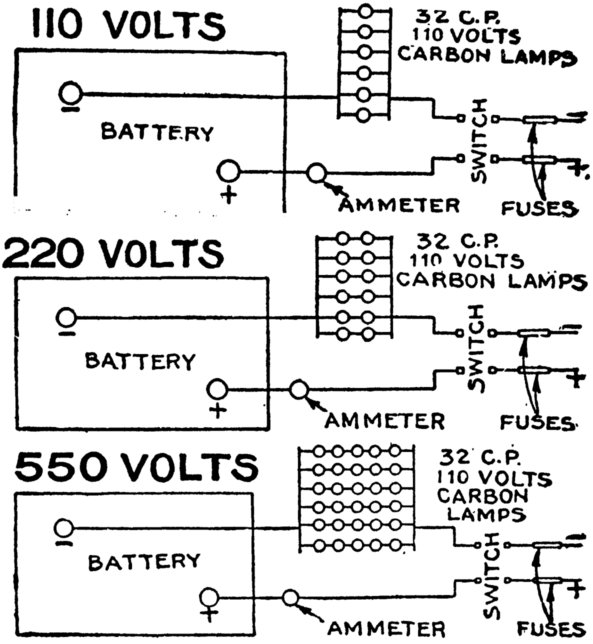


Fig. 1,721 to 1,723.—Charging through bank of lamps on 110, 220, and 550 volt circuit.

2. See that the vent plugs are in place.

3. Connect an approximate resistance, such as a proper size lamp, in series with the cells, across a charging system adapted for continuous charging. Fig. 1,724 gives an example of connections for trickle charge. The charging should be checked periodically and lamps changed if required until it is certain that the system gives neither too much nor too little charge.

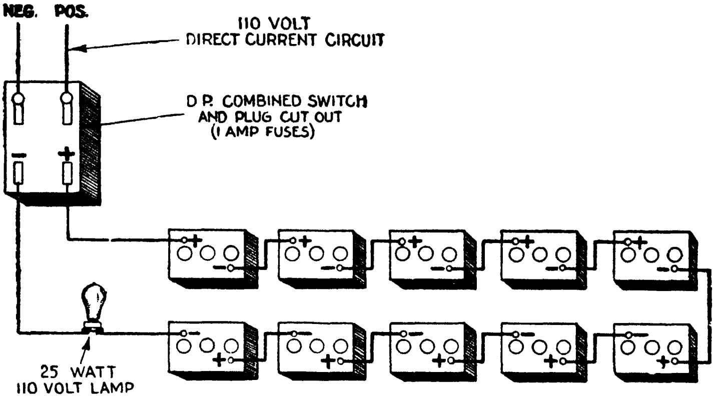
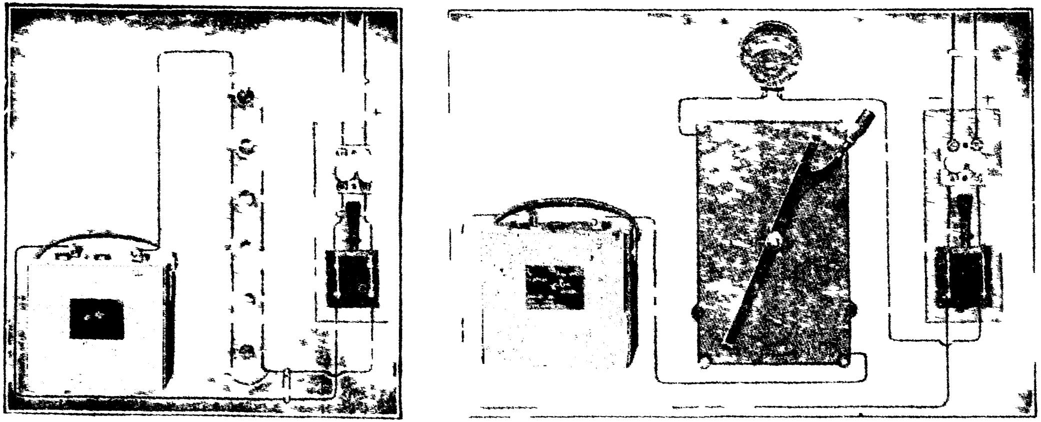


FIG. 1,724 —Trickle charge When a number of batteries are to be held in wet storage, the most satisfactory results can be obtained by charging continuously at a very low rate, which is so low that gassing is avoided and yet gives enough charge, to maintain the batteries in good condition This charge is called a *trickle charge* and in many cases will be found more convenient to arrange for than the perodic charge It has the added advantage of keeping the batteries in condition for putting into use at any time on short notice. ***To apply trickle charge:*** 1, give bench charge, 2, Connect a tungsten lamp or lamps of appropriate resistance, in series with the cells, across a charging system adapted for continuous charging. 3, Every two months interrupt the trickle charge, remove filling plug, add water to bottom of filling tubes, replace and tighten filling plug and continue trickle charge.

FIG. 1,725.—General Electric Tungar trickle charger for charging radio A battery. Capacity sufficient for 6 or 8 tube set



FIGS. 1,726 and 1,727.—Two methods of charging from a direct current lighting system. ***The simplest method*** of charging is from an incandescent light circuit, using lamps connected in parallel to reduce the voltage to that of the battery, the current being adjusted by varying the number of lamps in circuit. The group of lamps is in series with the battery to be charged, and the combination is connected across the circuit furnishing the current. If the charging source be a 110-120 volt circuit, and the rate required be 6 amperes, twelve 16 *c.p.* or six 32 *c.p.* lamps in parallel and the group in series with the battery, will give the desired charging rate, unless high efficiency lamps be used, when more will be required. In case a lower charging rate, say 2 amperes be used, then a proportionately fewer number of lamps will be needed, but the length of time required to complete the charge will be correspondingly increased. Instead of lamps as in fig. 1,726, a rheostat is sometimes used as shown in fig. 1,727. Its resistance should be such as to produce, when carrying the normal charging current, a drop in volts equal to the difference between the pressure of the charging source and that of the battery to be charged; thus, if a battery of three cells giving 6 volts is to be charged from a 110 volt circuit at a 6 ampere rate, the resistance would be, according to Ohm's law, neglecting internal resistance of the battery

$$(110-6) \div 6 = 17.3 \text{ ohms}$$

The carrying capacity of the rheostat should be slightly in excess of the current required for charging. An ammeter with suitable scale should be inserted in the battery circuit to indicate the current. For charging more than one battery at a time from a 110 volt circuit, the batteries should be connected in series (positive terminal of one battery to the negative of the next, and so on). The charging rate should be that of the battery with the lowest rate. The resistance to be inserted will be less than if only one battery is being charged; where lamp resistance is used ***this means more lamps in parallel***. Care should be taken to remove each battery from the circuit as it becomes charged, inserting additional resistance to take its place.

With proper resistance, the specific gravity will remain practically constant (within 10 to 15 points if level of electrolyte be kept the same height) and the cells will not be gassing. If the cells gas continually, the battery is receiving too much charge. If the gravity continue to drop, the battery is not receiving enough charge.

4. Every two months add water to the proper level and replace the vent plugs.

Periodic Charge Method.—This is a method of wet storage in which the batteries are given charges periodically, and is used where it is not practicable to arrange for the trickle charge method.

1. Give a charge until *all* the cells are gassing.

2. Store in a dry, clean location and keep the temperature above freezing and below 110 degrees Fahr.

3. Once every two months remove filling plugs, add distilled or other approved water to the proper level, replace and tighten vent plugs and charge until *all* the cells are gassing.

4. Before putting battery into service, add approved water and charge until *all* the cells are gassing.

Lamp Calculations for Charging.—To determine the proper size of lamps:

1. Find out the voltage of the charging circuit and the number of cells to be charged in series; for example, 100 volt circuit and 24 cells in series. If a rectifier be used for charging, the voltage should be that obtained with a *d.c.* volt meter, and while the battery is connected in circuit. It should be measured at the *d.c.* terminals of the rectifier.

2. Refer to one of the accompanying tables, the first one for 115 volt lamps and the other for 32 volt lamps. For example, in the first table the 100 volt column meets the 24 cell cross column at 215 watts. This means a 215 watt, 115 volt tungsten lamp in series with 24 cells across 100 volts would allow approximately 1 ampere charging rate at end of charge. The rate at the beginning of charge would be somewhat higher. Combinations of voltage and cells not shown in the tables can be approximated by proportion.

3. In the accompanying rating table (for Exide batteries) find the charge rate for the type and size of cell to be charged. For example, 6 amperes if the 24 cells be type XC-13. If cells with different charge rates are to be charged in series, use the charge rate of the cell having the lowest.

Multiply the watts, obtained in item 2 by the charge rate obtained in 3. For example. 215 watts multiplied by 6 equals 1,290 watts. The size of 115 volt tungsten lamp to use then is the nearest available commercial size to 1,290 watts. A larger size will allow a higher charge rate, and a smaller size a lower charge rate. Where the calculated watts and the wattage of the available lamps are considerably different, sufficient lower wattage lamps in parallel can be used, the sum of the watts of the different lamps being approximately equal to the calculated watts. For example, to obtain 1,290 watts, five 250 watt and one 40 watt lamps, all in parallel, may be used. The voltage rating of the lamps must be the same however; 115 volts in this example.

RATED WATTS OF 115-VOLT TUNGSTEN LAMPS
(To Give 1 Ampere)

	Charging Circuit Voltage								
Cells in Series	7.35	14.7	30	40	50	75	100	115	125
1	830	440	270	225	195	150	125	115	110
2	..	510	285	235	200	155	130	120	110
3	...	620	300	245	205	160	130	120	115
6	...	..	385	285	230	170	135	125	120
12	...	...	...	500	325	195	155	135	130
18	...	...	...	...	800	260	175	155	140
24	...	...	...	...	...	380	215	175	160
42	...	...	...	...	...	...	...	485	320

a. If a rectifier be used for charging, the wattage obtained in item 4 will have to be increased 25 to 50%. This is because the current obtained from a rectifier is pulsating and not steady as from a dynamo.

b. If the lamp resistance is to be used for trickle charging, divide the wattage obtained in item 4 by 50. For the example shown, this would be 1,290÷50≈25 watts approximately. If the calculated size be not available, use a lower voltage wattage lamp and not a higher.

Period of Charging a New Battery.—In the case of batteries provided with formed plates, the first charge should extend over a period of not less than 30 consecutive hours, without stopping, if possible, or for periods of not less than 10 hours a day for three consecutive days.

The electrolyte will then commence to "boil" or "gas," assuming a milky appearance due to the ascending bubbles of gas. At this stage the density of the electrolyte as shown by the hydrometer placed in each cell should be at least 1.200; it is essential that the charging should be continued until every cell boils equally. From this point the charging should be prolonged until the pressure, as determined by a volt meter or a cadmium tester, rises to about 2.55 volts.

RATED WATTS OF 32-VOLT TUNGSTEN LAMPS
(To Give 1 Ampere)

	Charging Circuit Voltage						
Cells in Series	7.35	14.7	30	40	50	60	75
1	100	55	35	30	..	..	..
2	...	65	35	30	25	..	..
3	...	80	40	30	25	..	..
6	...	..	50	35	30	25	..
9	...	..	75	45	35	30	..
12	...	..	..	65	45	35	25
18	...	..	..	..	95	50	35

The charging of unformed plates is similar in all respects to that of formed plates, except that the first charging should extend over a period of at least 70 consecutive hours without stopping, at the end of which time the plates should have the characteristic colors of those of a fully charged battery. If they do not, the charging should be prolonged and the cell tested for density of electrolyte, and voltage, as already described until the desired conditions are attained. Then the battery may be discharged and recharged.

It is probable that a total of 300 to 400 hours of charging with intervening discharges will be required to form the plates until they acquire a good color, and the density of the electrolyte becomes stable.

In regular charging, the rate should be rapid when the battery is nearly exhausted, but it should be greatly reduced at the end of the charge after passing the point of boiling. Charging at too low a rate is always injurious.

Ques. What may be said with respect to the capacity of a new battery?

Ans. A new battery will never give its full capacity till after about twenty discharges.

During this time it should be given about 25% overcharge. After that, 10% overcharge, that is, 10% more charge than was taken out, will be sufficient for ordinary work.

High Charging Rates.—Occasionally it is desirable to charge a battery as quickly as possible. As a general rule, such a procedure should not be adopted unless the battery be

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NOTE —*Example.* If a battery require about 3 amperes for charging, how is this current obtained from a 110 volt circuit? Each 16 candle power carbon filament lamp in the lamp bank would give approximately ⅓ ampere with the cells in series in the lamp circuit Therefore, 3×3 or 9 lamps should be used in parallel to give 3 amperes The amperes obtained will be slightly due to the opposition offered by the internal resistance of the battery

NOTE —*Selection of proper battery.* The number of *cells* is determined by the voltage of the system Thus, according to Gould

Voltage of System	Number of Cells	Voltage of System	Number of Cells
110	60	220	120
115	64	230	126
125	70	250	138

NOTE —The size of a 110 volt battery can be determined thus, assuming that the battery will be charged at any time during the day convenient to operate the dynamo and that the battery will be able to furnish current for lamps as follows

Time	Number of Lamps	3 Amperes	4 Number of hours	Ampere Hours col. 3 × col. 4
5. p m to 10 p m	Twenty 16 *c. p*	10	5	50
10 p m to 6 a m.	Two 8 *c. p.*	½	8	4
6 a m to 8 a m	Six 16 *c. p.*	3	2	6
				Total 60

thoroughly discharged, and not then, unless done by a person who thoroughly understands what he is about; battery makers will always furnish data and directions to meet emergencies.

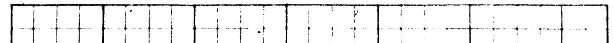


FIG 1,728 —Effect of temperature on capacity From an inspection of the curve, it is evident that the user who desires to obtain the full capacity of the battery must keep it at a temperature of not less than 80 degrees It is also evident that very little capacity is to be gained by allowing the temperature of the battery to rise above 80 degrees Fahr In fact, the gain is only about 5 per cent, and whatever is gained in this way is at the expense of the life of the plates and separators Temperature also affects the specific gravity of the electrolyte solution in batteries The specific gravity of the solution is with reference to a temperature of 80 degrees Fahrenheit, and comparative gravity readings are of little value unless the reading be corrected to a temperature of 80 degrees Fahrenheit As the temperature rises the acid solution in the battery expands in volume so that there is a smaller amount of sulphuric acid in each unit volume of the solution Since each unit volume contains less acid, each unit will weigh less or have a lower specific gravity Because of this, the gravity reading must be decreased one point for each three degrees rise in temperature ***For example,*** if the gravity at 80 degrees be 1 280 and the temperature rise to 98 degrees, the gravity of the solution will have decreased to 1 274 Low temperatures do no actual harm to a battery in a fully charged condition, except to lower its capacity A discharged battery will, however, freeze at points above zero and freezing usually results in a ruined battery. The temperatures at which different gravities of electrolyte freeze are shown in the curve in fig 1,729.

In charging a battery at a high rate, the danger to be avoided is the tendency of the cells to heat. The troubles that might arise from this cause may be prevented by immediately reducing the current strength.

The proper rate of charge for a given battery of cells may be thus discovered by experiment. A battery should never be charged at a high rate unless it be completely exhausted, since it is a fact that the rate of charge that it will absorb is dependent upon the amount of energy already absorbed.

For rapid charging, when a battery has to be charged in four hours, the current should vary about as follows:

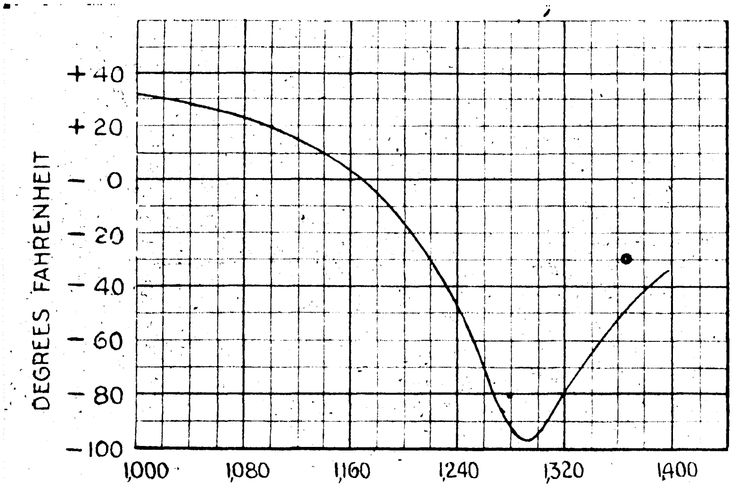


FIG. 1,729.—Freezing points of electrolyte of different specific gravities.

40 per cent. of total 1st hour
25 " " " " 2nd "
20 " " " " 3rd "
15 " " " " 4th "

For quick charging in three hours the rates should be: 50 per cent. 1st hour; 33⅓ per cent. 2nd hour; 16⅔ per cent. 3rd hour.

Ques. Why do the gases evolved produce a less milky appearance of the electrolyte when a battery has been in use for a considerable time?

Ans. The plates are better formed; consequently a larger charging current can be used without producing "boiling."

Capacity.—The unit of capacity of a storage cell is the *ampere hour*, that is, *the ability to discharge one ampere continuously for one hour.*

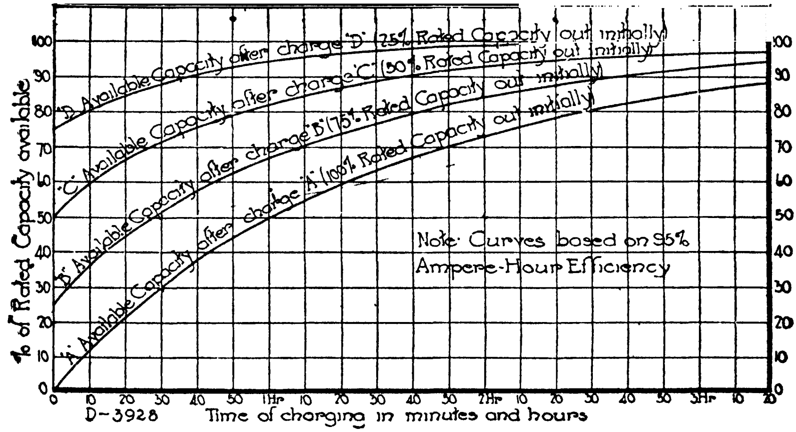


Fig. 1,730.—Available capacity of Exide-Ironclad battery.

For instance, a 100 ampere hour battery will give a continuous discharge of 12½ amperes for eight hours. It should theoretically give a discharge of 25 amperes continuously for four hours, or 50 amperes for two hours, but in reality, the ampere hour capacity decreases with an increase of discharge rate.

It requires, theoretically, .135 oz. of metallic lead on either element reduced to sponge lead or to lead peroxide to produce one ampere hour; in practice, from four to six times this amount is required.

The reason for this is because it is impossible to reduce all the active material, to bring every particle in contact with the electrolyte, or to cause every part to be penetrated by the current.

Experiments show that from .5 to .8 oz. of sponge lead, and from .53 to .86 oz. of metallic lead converted into peroxide, are required on their respective elements to produce a discharge of one ampere hour at ordinary commercial rates.

The capacity increases with the temperature, being about one per cent. for each degree Fahr. increase in temperature.

Battery capacity depends on the size and number of plates; the quantity of active material present, and the quantity of electrolyte.

For an eight hour rate of discharge and 60 degrees temperature, the capacity of American batteries varies from 40 to 60 ampere hours per square foot of positive plate surface (=2×number of positive plates in parallel×length×breadth).

The following table gives the variation of capacity for different rates of discharge:

Capacity Variation for Different Discharge Rates

Discharge rate	Per cent of capacity at 8 hour rate	
	Planté	**Faure**
8 hour............	100%	100%
6 hour............	96%	96%
4 hour............	80%	88%
2 hour............	61%	70%
1 hour............	56%	48%

Ques. How may the capacity of a battery be increased?

Ans. By mixing organic materials with the lead oxide, *but any such mixture is always accompanied by a rapid deterioration of the plates.*

Discharging.—In discharging a battery its voltage should never be allowed to fall below 1.8 volts, under load, thus leaving about 30 per cent. of the total capacity unused.

The normal discharging current may be equal to the normal charging current, but a discharge equal to 3 or 4 times the normal may be given without injury to the plates.

Some types may be discharged at even six or seven times the normal rate. In such cases, however, the capacity will be reduced in the same proportion, as before explained in the paragraph dealing with battery capacities.

Ques. What is the effect of discharging too rapidly?

Ans. It tends to break the plates, and in the case of pasted plates, a very sudden discharge will dislodge the paste.

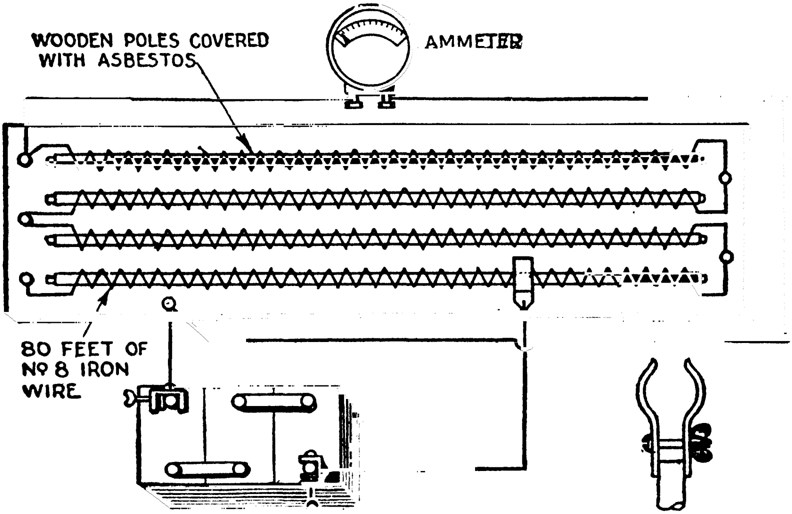


FIG. 1,731 and 1,732.—Home made discharge rheostat. The terminal on the end of the cable attached to the right hand terminal of the battery as shown, is movable, and it may be clamped at any point along the coils of wire so as to give various currents. The wire should be greased lightly to prevent rusting.

Ques. How is the discharge capacity of a storage battery stated?

Ans. In ampere hours.

This, unless otherwise specified, refers to its output of current at the eight hour rate. Most manufacturers of automobile batteries specify only the amperage of the discharge at three and four hours. Thus, at the eight hour rate, a cell which will discharge at ten amperes for eight hours is said to have a capacity of eighty ampere hours.

It does not follow that eighty amperes would be secured if the cell were discharged in one hour. It is safe to say that not more than forty amperes would be the result with this rapid discharge.

As a general rule, the one hour discharge rate is four times that of the normal, or eight hour discharge, and considerations of economy and prudence suggest that it should never be exceeded, if, indeed, it ever be employed. The three hour discharge, which is normally twice that of the eight hour, is usually the highest that is prudent, while the four hour discharge is the one most often employed in automobiles for high speed driving.

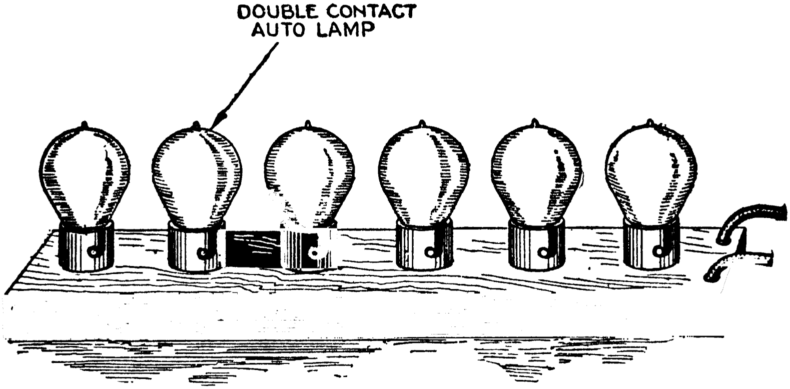


FIG. 1,733.—Another home made discharge apparatus. *In construction* six double contact automobile lamp sockets are mounted on a board and all connected in parallel; a pair of leads having test clips attached is brought out from the sockets for fastening to the battery terminals. Lamps of various candle power may be turned into the sockets to obtain different currents.

Ques. What should be the maximum rate of discharge?

Ans. The one-hour rate; this when used, should not extend over fifteen or twenty minutes.

In the case of regulating batteries a forty-five minute rate of discharge may be allowed for one or two minutes during great fluctuations of load.

Ques. How does the capacity decrease?

Ans. It decreases with the increase in current output.

An 80 ampere hour cell, capable of delivering 10 amperes for 8 hours, would, when discharged at 14 amperes, have a capacity of 70 ampere hours; when discharged at 20, its capacity would be 60; and when discharged at 40, its capacity will have decreased from 80 to 40 ampere hours.

Ques. What, in general, are the indications of the quantity of electricity remaining within a cell?

Ans. The voltage, and the density of the electrolyte.

Ques. What should be done after discharging?

Ans. Whenever possible the battery should be immediately charged.

TEST QUESTIONS

1. *How should a battery be charged for the first time?*
2. *What is the usual period for charging a new battery?*
3. *How is the electrolyte affected by the first charge?*
4. *What strength of current should be used in charging a cell?*
5. *On what kind of a battery charging circuit should a discriminaing cut-out be used?*
6. *What indicates the completion of a charge?*
7. *How should the cadmium test be made?*
8. *What instrument is used to determine the state of charge?*

9. *What is the effect of varying the charging current?*
10. *How is the state of the charge indicated by the colors of the plate?*
11. *What should be the density of electrolyte of a fully charged battery?*
12. *Name two ways of charging batteries.*
13. *Describe the behavior of the electrolyte during discharge.*
14. *Define the term "boiling"; what causes it?*
15. *Explain how batteries should be charged during the night.*
16. *What precautions should be taken in charging a battery out of a vehicle?*
17. *How are small cells easily charged from 110 or 220 volt circuit?*
18. *Describe the triple charge method.*
19. *What may be said with respect to the capacity of a new battery?*
20. *How may a battery be charged at a high charging rate?*
21. *How may the capacity of a battery be increased?*
22. *What is the effect of discharging a battery too rapidly?*
23. *How is the discharge capacity of a storage battery stated?*
24. *Describe the term "ampere hours."*
25. *What should be done after discharging a battery?*

CHAPTER 45

Storage Battery Repairs

Tools, Equipment and Spare Parts.—Anyone undertaking to care for or repair batteries will in time gather together the equipment he considers necessary or desirable for the work. Many of the tools are questions of personal taste or present equipment, but there are four things absolutely necessary:

1. Suitable charging equipment.
2. Hydrometer syringe.
3. Battery thermometer.
4. Lead burning outfit.

In addition, tools and equipment must be available for the following purposes, and suggestions are here given along with the list of purposes:

1. To read battery or cell voltage: portable volt meter, such as Weston model No. 279.
2. To remove connectors: a brace with $\frac{5}{8}$, $\frac{3}{8}$ and $\frac{1}{8}$ in. wood bit.
3. To tighten or loosen seal nuts: A special wrench. There are three sizes.
4. To tighten or loosen tie bolts: a screw driver or else special spanner bit.
5. To unseal covers: a putty knife.
6. To remove element from jar: two pairs of 6 in. or 8 in. gas pliers.
7. To prepare surfaces for lead burning: knife, scraper, shoemaker's rasp, wire brush, file or end cutting pliers.
8. To handle sealing compound: receptacles in which to heat and from which to pour.
9. To handle electrolyte: non-metallic or lead vessels for storing, mixing and pouring: rubber gloves or fingers for protection; soda or ammonia solution for neutralizing effects of spillage or sloppage.
10. To make moulds for lead burning; pieces of iron, tin or powdered asbestos and a pair of tin snips.

11. To provide for the actual work: a strong wooden work bench painted with acid resisting paint, strong racks for holding cells and a lead lined sink for washing jars.

A stock of spare battery parts should of course, be kept on hand, and with these should be included:

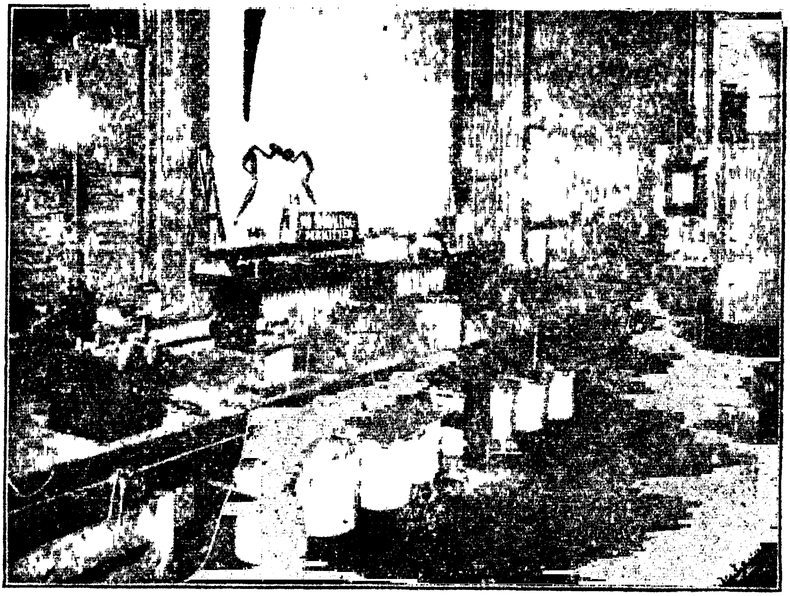


FIG 1,734 —Typical work room showing bench about 34 ins high lead burning outfit, hot plates for melting sealing compound and hand drill press for drilling off inter-cell connectors

1. Sealing compound for resealing cells
2. Burning strip for lead burning
3. Electrolyte for replacing actual spillage or loss and never for normal operation.
4. Acid resisting paint for painting cases, racks, etc
5. Pure petroleum grease for terminals to prevent corrosion.
6. New packing material to replace acid-soaked packing.

GLOSSARY

Acid: Term frequently used to describe the liquid in cells, in place of the approved one: *electrolyte*.

Active Material: The "formed" paste which fills the grid.

Ampere: The unit of measure of quantity of electric current

Ampere Hours: Product of amperes and hours

Battery: Any number of cells when connected and used together.

Bridge (***or rib***)***:*** Wedge shaped vertical projection from bottom of rubber jar on which plates rest and by which they are supported

Burning: A term used to describe the operation of joining two pieces of lead by melting them at practically the same instant so they may run together as one continuous piece. Usually done with mixture of oxygen and hydrogen gases, hydrogen and compressed air, or oxygen and illuminating gas.

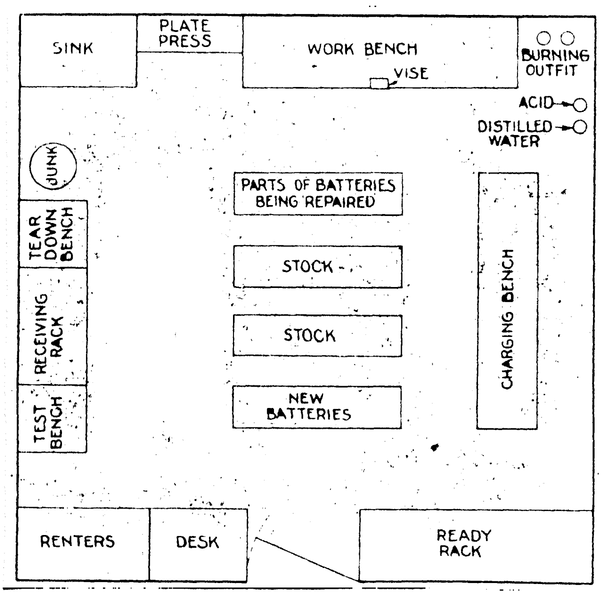


FIG. 1,735.—Plan of a small battery repair shop.

Cadmium: A metal used in about the shape of a pencil for obtaining voltage of positive or negative plates It is dipped in the electrolyte but not allowed to come in contact with plates

Capacity: The rating of cell or battery in ampere-hours, qualified by the rate or time of discharge

Case: The box which holds the cells of a battery

Cell: Unit of storage battery practice, consists of elements, electrolyte and jar.

Charge: Passing direct current through a battery in order to replace energy used on discharge

Charging Rate: The proper rate of current, expressed in amperes to use in charging a battery.

Connector: Solid or flexible part for connecting positive pole of one cell to negative pole of another, or to terminal

Cover: Cover for cell to retain electrolyte and exclude foreign material

Cycle: One charge and discharge

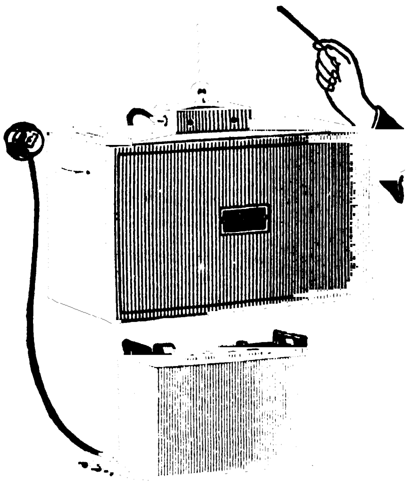


FIG 1,736 —Electrically heated oven used for opening storage batteries It is large enough to accommodate any size starting or lighting battery ***In operation,*** place the battery on the work bench, lower the heater over it, turn on the switch, and in five minutes the sealing compound is softened so that the elements and jars can be easily removed

Density: Specific gravity

Developing: The first cycle or cycles of a new or rebuilt battery to bring about proper electrochemical conditions to give rated capacity

Diffusion: Pertaining to movement of acid within the pores of plates (See ***Equalization***)

Discharge: The flow of current from a battery through a circuit, opposite of "charge "

Dry: Term frequently applied to cell containing insufficient electrolyte

Electrolyte: The conducting fluid of electro-chemical devices, for lead-acid storage batteries consists of about two parts of water to one of chemically pure sulphuric acid, by weight

Element: Positive group, negative group and separators

Equalization: The result of circulation and diffusion within the cell which accompanies charge and discharge. Difference in capacity at various rates is caused by the time required for this feature.

Equalizing: Term used to describe the making uniform of varying specific gravities in different cells of the same battery, by adding or removing water or electrolyte.

Evaporation: Loss of water from electrolyte from heat or charging.

Forming: Electro-chemical process of making pasted grid or other plate types into storage battery plates. (Often confused with *Developing*.)

Foreign Material: Objectionable substances.

Freshening Charge: A charge given to a battery which has been standing idle, to keep it fully charged.

FIG. 1,737.—Combination cell tester for open voltage and cadmium tests. It does away with separate meter and prods. Cadmium extension removable for immersion when not in use.

Gassing: The giving off of oxygen gas at positive plates and hydrogen at negatives, which begins when charge is something more than half completed, depending on the rate.

Gravity: Common term for specific gravity.

Grid: Cast or stamped frame-work in which active material is retained.

Group: Any number of positive *or* negative plates properly joined together.

Hold-down: Device for keeping separators from floating or working up.

Jar: Container for element and electrolyte. Usually of hard rubber.

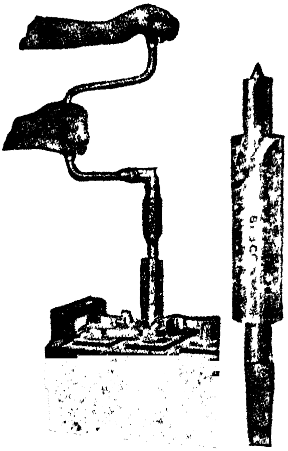
Lug: Vertical projection from grid for connecting with and burning to strap.

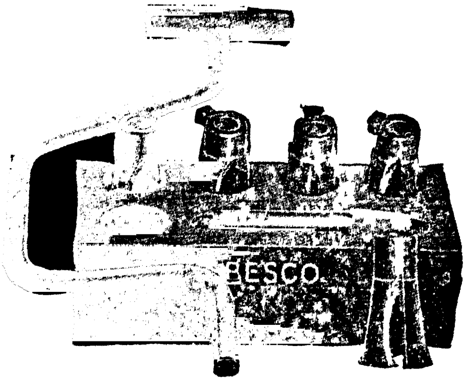
Mud: (See *Sediment.*)

Nipple: A sleeve or distance piece placed over terminals to separate covers of a double cover cell.

Over Charge: Continuance of charge beyond that apparently or supposedly necessary to improve condition of cells.

Over Discharge: The carrying of discharge beyond proper cell voltage; shortens life if carried far enough and done frequently.





Figs. 1,738 and 1,739 —Besco post drill. Fig. 1,738, operation of drill; fig. 1,739 view of drill. ***In operation,*** it drills down a battery post through the cell connector, leaving the connector and the post intact and usable. The post drill is useful in tearing down batteries, saving the material for rebuilding the battery again.

Fig. 1,740 —Post reducers. ***Used*** to trim battery posts to proper size for terminal connectors or point them for burning ***The cutters*** have 10° taper and range in size from 11/16 to ⅞ in. opening.

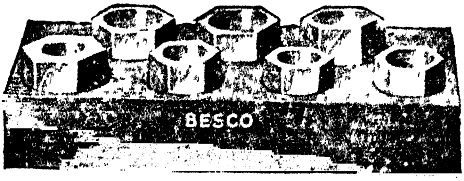


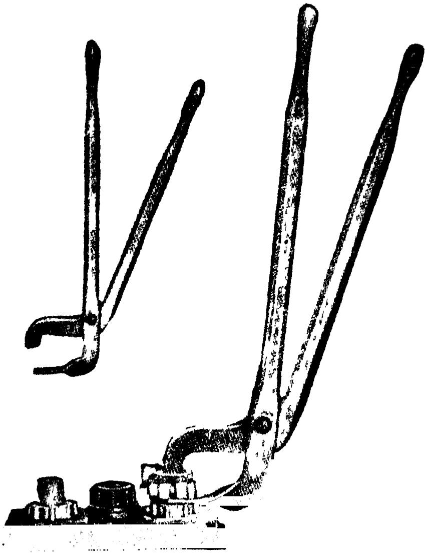
Fig. 1,741.—Post builders. When a battery is opened the posts of the plate straps must be drilled down and again built up on assemblage. There are seven necessary sizes, ranging from ½ to ⅞ in.

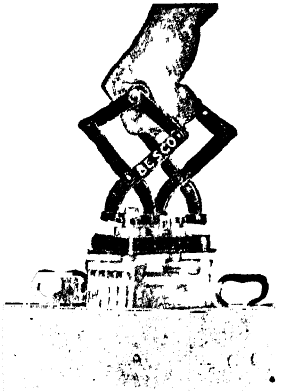
Paste: The mixture of lead oxide or spongy lead and other substances which is put into grids.

Plate: The combination of grid and paste properly "formed." Positives are reddish brown and negatives slate gray.

Polarity: An electrical condition. The positive terminal (or pole) of a cell or battery or electrical circuit is said to have positive polarity; the negative, negative polarity.

Post: The vertical cylindrical part of strap which receives connector.





FIGS. 1,742 and 1,743.—Besco terminal extractor. Fig. 1,742, extractor; fig. 1,743, application. ***It is used*** for removing brass terminal connectors that are badly corroded and stick tight to the post Because of the great force necessary to pull stubborn connectors, it is necessary to make this tool out of the very best drop forged stock. Contains sufficient leverage to exert great pressure.

FIG. 1,744 —Besco group puller. Plates, separators and groups of a battery expand in service and with age, making it difficult to extract them when disassembling a battery. Pulling groups with pliers is unsatisfactory; jars are broken, posts are chewed off, hands are bruised and great effort is expended without results. This puller has a vise-like grip and the harder the pull, the more it grips. An even pull is distributed to both posts, making easy extraction without wedging the group which ordinarily breaks the rubber jar.

Potential Difference: Abbreviated P.D. Synonymous with voltage.

Rate: Number of amperes for charge or discharge. Also used to express *time* for either.

Rib: (See *Bridge*.)

Ribbed: (See *Separator*.)

Reversal: That which occurs to voltage readings when cells are discharged below a certain critical point or charged in the wrong direction.

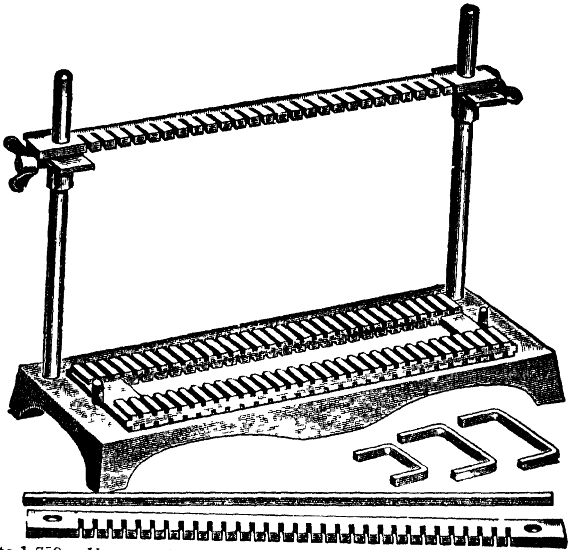
Sealing: Making tight joints between jar and cover; usually with a black, thick, acid proof compound.

Sediment: Loosened or worn out particles of active material fallen to the bottom of cells; frequently called "mud."

Sediment Space: That part of jar between bottom and top of bridge.

Separator: An insulator between plates of opposite polarity; usually of wood, rubber or combination of both. Separators are generally corrugated or ribbed to insure proper distance between plates and to avoid too great displacement of electrolyte.

Spray: Fine particles of electrolyte carried up from the surface by gas bubbles. (See *Gassing.*)



FIGS 1,745 to 1,750 —Universal lead burning rack This rack will handle all types of starting and lighting plates. The base is heavy cast iron with the grooves for holding plates cut in a separate piece, one side of which is grooved for 7/16" spacing and the other for ⅜". It is equipped with pins fitting into three holes in the base, which will space it correctly for plates with lugs at the corner or with lugs offset Two combs or spacing bars are provided, one is made for twenty-seven ⅛" plates and the other for thirty-one 5/32" plates. These combs are adjusted to the proper height with thumb screws as shown.

Strap: That part to which all plates of one group are burned.

Sulphate: Common term for lead sulphate. ($PbSO_4$.)

Sulphated: Term used to describe cells in an under charged condition, from either over-discharging without corresponding long charges or from standing idle some time and being self-discharged.

Sulphate Reading: A peculiarity of cell voltage when plates are considerably sulphated, where charging voltage shows abnormally high figures before dropping gradually to normal charging voltage

Terminal: Part to which outside wires are connected.

Vent or ***Vent Cap:*** Hard or soft rubber part inserted in cover to retain atmospheric pressure within the cell, while preventing loss of electrolyte from spray.

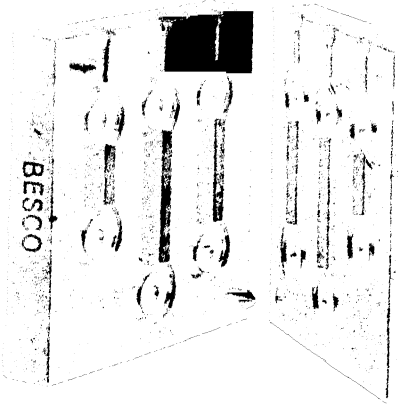
Voltage: Electrical pressure or potential difference, expressed in volts.

Wall: Jar sides and ends

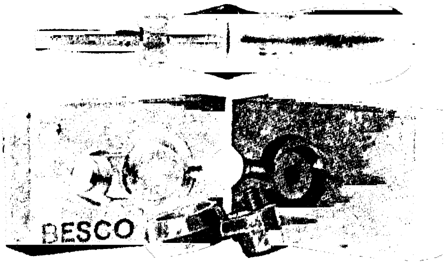
Washing: Removal of sediment from cells after taking out elements, usually accompanied by rinsing of groups, replacement of wood separators and renewal of electrolyte.

Watts: Product of amperes and volts.

Watt-Hours: Product of amperes, volts and time in hours.



Figs 1,751 and 1,752 —Besco gang connector mould. Where only three of the popular sizes (7-11-13) cell connectors are desired, this gang connector mould will fill that requirement. The construction is rugged for moulding double taper castings A sufficient quantity of iron is used to retain the heat for continuous operation



Figs. 1,753 and 1,754 —Besco radio terminal mould. It is so made that different lengths of 5/16 in screws may be used.

Inspecting a New Battery.—On receipt of the battery it should be wiped clean of dust and particles of packing, and the nipples should be discarded. The case should be carefully examined and if there be evidence of damage in transit, claim should immediately be made against the carrier.

Remove the vent caps from the cells and determine the height of the solution in each cell If the height of the solution in all the cells be uniform, there is no indication of a leaky jar

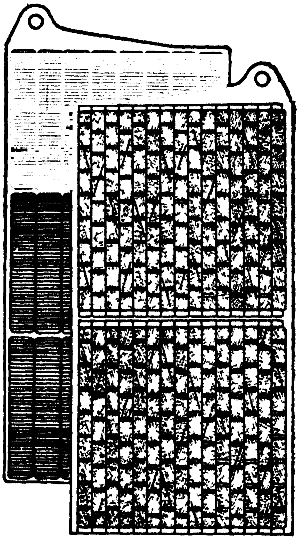
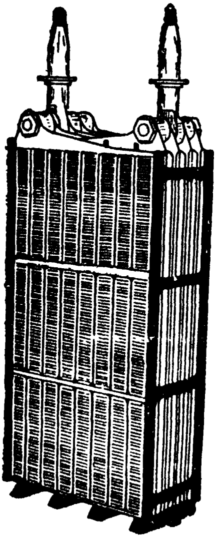


FIG. 1,755 —Plates of Edison storage battery The positive or nickel plate consists of one or more perforated steel tubes, heavily nickel plated, filled with alternate layers of nickel hydroxide and pure metallic nickel in excessively thin flakes The tube is drawn from a perforated ribbon of steel, nickel plated, and reinforced with eight steel bands, equidistant apart, which prevent the tube expanding away from and breaking contact with its contents The tubes are flanged at both ends and held in perfect contact with a steel supporting frame or grid made of cold rolled steel, nickel plated The negative or iron plate consists of a grid of cold rolled steel, nickel plated, holding a number of rectangular pockets filled with powdered iron oxide These pockets are made up of very finely perforated steel nickel plated After the pockets are filled they are inserted in the grid and subjected to great pressure between dies which corrugate the surface of pockets and force them into good contact with the grid

In a new battery, the density of the solution in the cells should read 1.275 to 1 285 or somewhat less, depending on the elapsed time since the battery left the factory, temperature conditions, etc If the density of the solution read below 1 250 the battery should be given a freshening charge until the hydrometer shows a density of 1 280 to 1 290 Care should be taken to charge in the proper direction, the positive terminal of the battery should be connected to the positive side of the charging system Replace the vent caps, screwing them in tightly, and place the battery on a clean, dry spot for 24 hours as an extra test for a leaky jar, and note whether there be any dampness in the battery.

Preparing New Batteries for Service.—Upon receipt of a



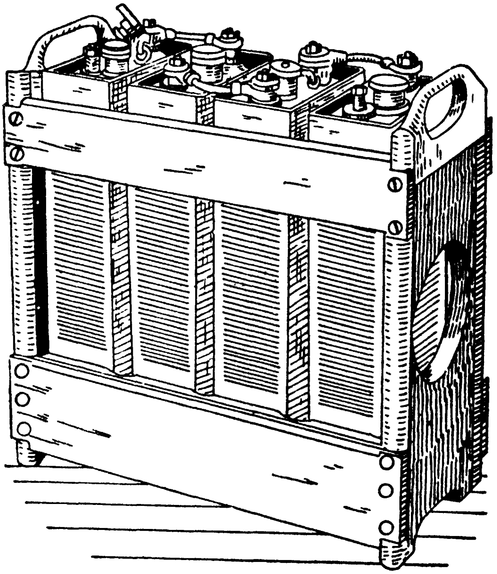


Fig. 1,756.—Complete element of Edison storage battery with insulators. After the plates are assembled into a complete element, narrow strips of treated hard rubber are inserted between the plates, thereby separating and insulating them from each other. The side insulator is provided with grooves that take the edges of the plates, thereby performing the dual function of separating the plates and insulating the complete elements from the steel container. At the ends of the element, that is between the outside negative plates and container, are inserted smooth sheets of hard rubber. At the bottom, the element rests upon a hard rubber rack or bridge, insulating the pates from the bottom of container.

Fig. 1,757.—Four Edison cells (type A-4) in wooden tray.

NOTE.—*If two pieces* of very thin bright steel be placed out of doors for a few weeks, they become rusted. The action of the oxygen on the outer layer of the metal has formed it into an oxide commonly known as "rust." Now place these two pieces of steel in a solution composed of potash and water, and connect them by wires to a small dynamo. The electricity, in flowing from the dynamo through the solution, from one of the plates to the other and back to the dynamo, changes the rust to metallic iron on one of the plates, but causes the other plate to become "rusted" twice as much as before.

new battery, after making an inspection as directed in the previous paragraphs, proceed as follows:

1. Determine whether the battery has been shipped
   - *a.* Charged
   - *b.* Unfilled.
   - *c.* Dry.
   - *d.* Dry charged.

A charged battery is one in which the electrolyte has been added and

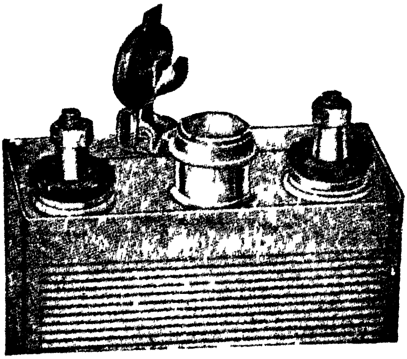
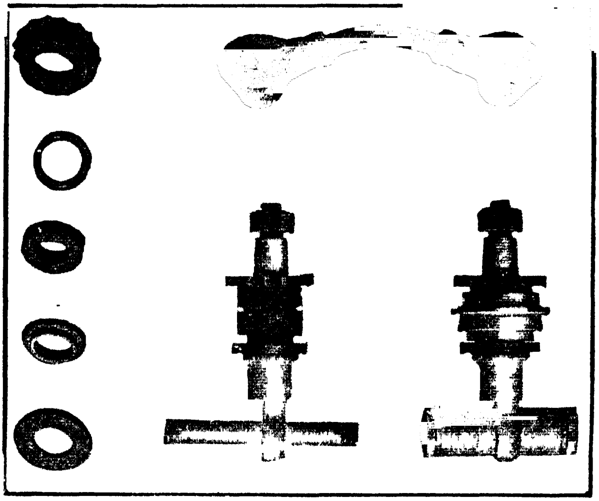


FIG. 1,758.—Top of Edison cell showing check valve and filling aperture for adding distilled water.

NOTE.—***Chemistry of the Edison Storage Battery.*** The fundamental principle of the Edison storage battery is the oxidation and reduction of metals in an electrolyte which neither combines with nor dissolves either the metals or their oxides. An electrolyte also, notwithstanding its decomposition by the action of the battery, is immediately reformed in equal quantity, and is, therefore, a practically constant element without change of density or conductivity over long periods of time. Therefore, only a small quantity of such electrolyte is necessary, permitting a very close proximity of the plates. Furthermore, it is unnecessary to take hydrometer readings until about 300 cycles of charge and discharge have been made, this is simply to determine when it is necessary to empty out the old solution and put in new. The active materials of the electrodes being insoluble in the electrolyte, no chemical deterioration takes place therefrom. The chemical reactions in charging the Edison storage battery are, the oxidation from a lower to a higher oxide of nickel in the positive plate, and the reduction from ferrous oxide to metallic iron in the negative plate. The oxidation and reduction are performed by the oxygen and hydrogen set free at the respective poles by the electrolytic decomposition of water during the charge. The charging of the positive plate is a process of increasing the proportion of oxygen to nickel given an initial charge It is shipped in a fully charged condition and with the proper amount of electrolyte in the cells.

An unfilled battery is one which has been assembled with damp, treated separators, without electrolyte ever having been added and with plates which require an initial charge.

A dry battery is one which has been assembled with dry separators, without electrolyte ever having been added but with the plates in a charged condition.



FIGS. 1,759 to 1,766 —Edison storage battery construction. The arrangement here shown makes a gas tight and liquid tight packing between the top of the container and the poles. The steel lugs of the standard connector shown at the top are exactly tapered to fit the tapered steel poles. When forced into position by the pole nuts, the contact is made perfect.

2. To each unfilled, dry or dry charged battery there is attached an identifying tag or label before the battery is shipped.

If battery has been shipped charged:

1. Remove vent plugs and examine height of electrolyte; if it be at or below the top of the separators, add suitable water until level of the solution is just below the bottom of the filling tubes. If there be evidence that

electrolyte has been lost from any cells in transit, use electrolyte instead of water to make up the loss on these cells. The specific gravity of this electrolyte should be the same as that in the surrounding cells. After adding water, replace and tighten plugs and give the battery a charge. If for any reason, the battery stand idle for a considerable period, make sure it receives the attention required by a battery in wet storage.

2. Shortly before the battery goes into service give a freshening charge, continuing charge as long as the specific gravity of the lowest gravity cell shows any increase and then for at least 5 hours after the last increase is shown, so that the charge is continued until the specific gravity has stood still for 5 hours.

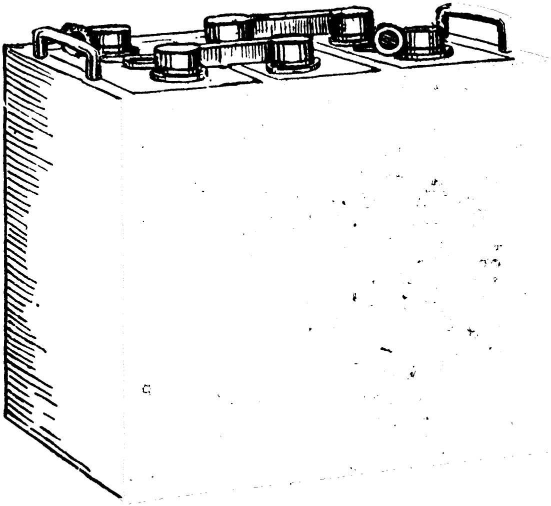


FIG. 1,767.—*Battery repairs 1.* A Gould 6 volt 81 ampere hour storage battery used for starting and lighting. This battery was returned for repairs.

If wood insulated battery has been shipped uncharged:

1. Remove the vent plugs and fill each cell with 1.335 (36.4 Baume) specific gravity electrolyte, which consists of one part (by volume) of pure

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NOTE.—***A storage battery*** is commonly looked upon as a receptacle in which to store electricity. Electricity is not concrete matter. In fact, nobody knows just what it is. Therefore, in the general apprehension of the term, it is not stored. Electricity simply causes a chemical change to be effected in certain substances, when it is caused to flow through them. These substances, in endeavoring to return to their original state, produce electricity.

sulphuric acid suitable for batteries, to two parts of distilled water, to ⅜ in. above tops of the separators.*

2. Wait 5 minutes and then fill each cell again with 1.335 (36.4 Baume) specific gravity electrolyte to ⅜ in. above the tops of the separators.

3. The battery must then stand from 10 to 15 hours before it can be placed on charge.

4. After standing for this length of time, fill each cell again, if necessary, with 1,335 (36.4 Baume) specific gravity electrolyte to bring the level of the electrolyte ⅜ in. above the top of the separators before charging.

5. Place the battery on charge at the finish rate marked on the name plate (or as shown on the chart supplied) until the gravity and cell voltage stop rising. This charging will require at least 84 hours.

6. The gravitv of a fully charged battery varies between 1.280 and 1.300 (31.8 and 33.5 Baume). If, after a charge of 84 hours or longer, the specific gravity does not rise for two consecutive hours, the gravity should be between 1.280 and 1.300 (31.8 and 33.5 Baume). If it be not between these limits, the specific gravity should be adjusted to these values at the end of the charge.

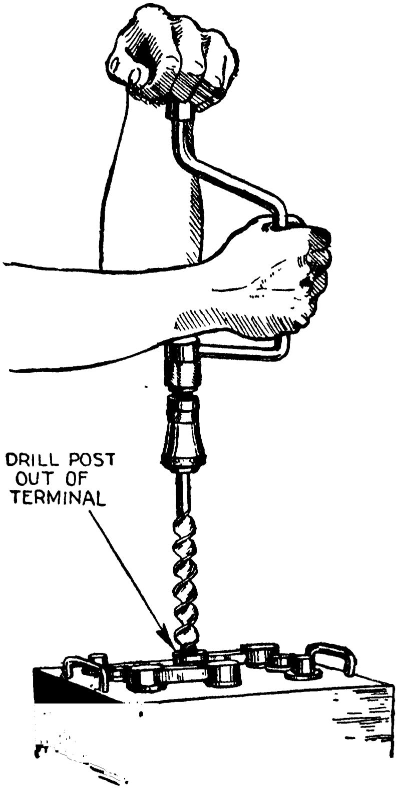
DRILL POST OUT OF TERMINAL

FIG. 1,768.—***Battery repairs 2.*** To remove terminal or connecting link, drill down to a depth of ¾ in. using a ⅛ in. drill. Then follow up with a ⅝ or 11/16 in. drill. Do not drill deeper than necessary so as to minimize the labor of building up the post. Where a torch is available instead of drilling, play flame on the center of the post and melt a hole in it. Drilling destroys the post.

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*NOTE.—Never fill with freshly mixed electrolyte that is over 90° F. (32° C) in temperature.

7. If, during the charge, the temperature exceed 110° Fahr. (43° C.) the charge rate should be reduced so as to keep the temperature below 110° Fahr. (43° C.) and the time of charging lengthened proportionately.

NOTE.—Special reference to the Willard wood insulated battery.

If rubber insulated battery has been shipped uncharged:

1. Remove the vent plugs and fill the battery to the top of the vent opening with 1.275 specific gravity electrolyte (31.3 Baume).
2. Wait 5 minutes and fill again to the same point with the same gravity electrolyte.
3. The battery must now be left standing at least 12 hours and not more than 24 hours before charging. This is done to permit the acid to penetrate the active material, which is a necessary step in the preparation of the battery. While thus standing the level of the electrolyte will drop, due to the absorption of electrolyte in the pores of the plates and insulation.
4. Just before charging, fill the battery again with the same gravity electrolyte as mentioned above, up to the under part of the vent holes.

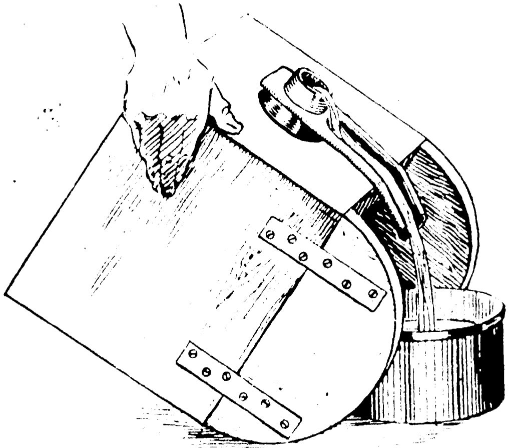


FIG. 1,769.—Method of drawing acid from a carboy. The combination of a large glass bottle encased in a wooden box is called a carboy. Attach to box two rockers and fit a piece of inner tube to neck of bottle as shown. This will permit pouring the liquid without spilling even when the bottle is full.

After this do not fill the battery with anything but distilled water.

5. The battery should then be on charge at finish rate shown on name plate, or as shown on the chart supplied. This should be prolonged until the specific gravity stops rising. At tne end of the charge the specific gravity should be between 1.280 and 1.300 or 31.7 to 33.5 Baume, which may take 36 to 72 hours.

6. Due to the charging process it is very likely that the water will evaporate in which case the level of the electrolyte will go down. Distilled water should then be added so that the plates are entirely covered with electrolyte, which should be about ⅜ in. above them. The important matter to observe is the temperature of the electrolyte, which should not exceed 110° Fahr. (43° C.). Should the temperature rise above this point, battery cnarging should be discontinued for a while or the rate of current decreased. If the gravity stop rising for two consecutive hours, it is a sign that the battery is fully charged, and the only thing necessary is to equalize the specific gravity in the cells so that they shall be about the same. For instance, if the specific gravity of electrolyte in one cell be over 1.300, remove a certain amount of electrolyte replacing it with distilled water. Similarly if the specific gravity be below 1.275 remove a certain amount of electrolyte and add the same amount of 1.400 sulphuric acid. The charging should then be continued for another hour so as to get the solution mixed

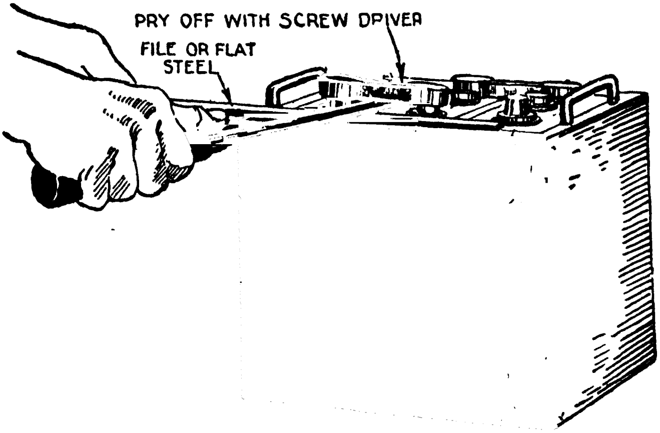

PRY OFF WITH SCREW DRIVER
FILE OR FLAT STEEL

FIG. 1,770.—*Battery repairs 3.* In removing the top connectors, place a file or a flat piece of steel along the edge of the case. Place an ordinary screw driver underneath the connector and pry it off. The object of the file or piece of steel is to protect the case from breakage.

properly. Care should be taken not to prolong the charging unduly, for that would be bound to injure the plates, causing the material to fall from the grids. On finishing the charging of battery the vent plugs should be replaced.

Preparing the Electrolyte.—The electrolyte is the solution in the battery and consists of a definite mixture of pure sulphuric acid and distilled or other suitable water. The sulphuric acid must be chemically pure.

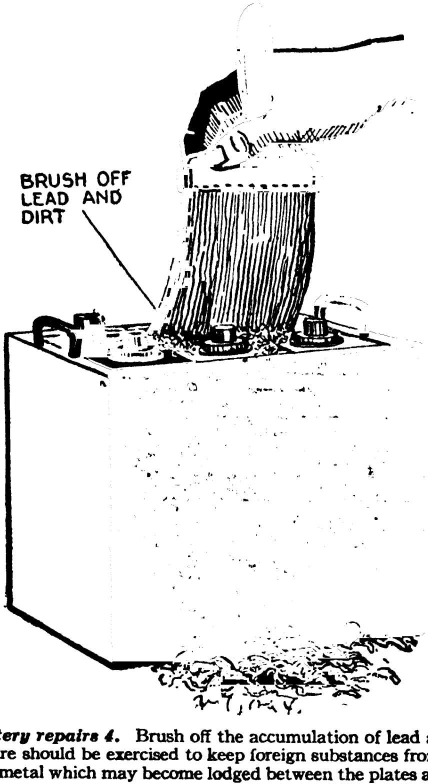


FIG. 1,771.—***Battery repairs 4.*** Brush off the accumulation of lead and dirt from the top of the battery. Care should be exercised to keep foreign substances from the inside of the battery, especially metal which may become lodged between the plates and separators and eventually cause short circuiting.

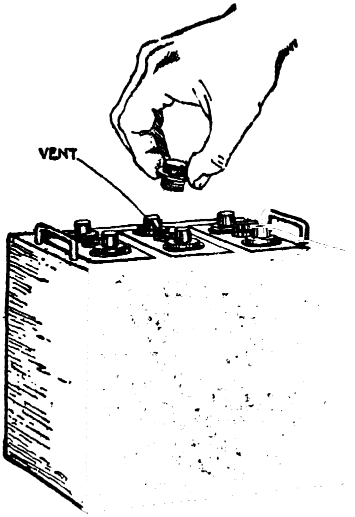


FIG. 1,772.—***Battery repairs 5.*** Remove vent plug. This should be done before using a flame around the battery, because hydrogen gas is generated in a battery and its presence may cause an explosion. This gas can be quickly expelled by blowing into the cells with a bellows. As the vent plugs are made of hard rubber, which is easily broken, do not attempt to remove them with a pair of pliers.

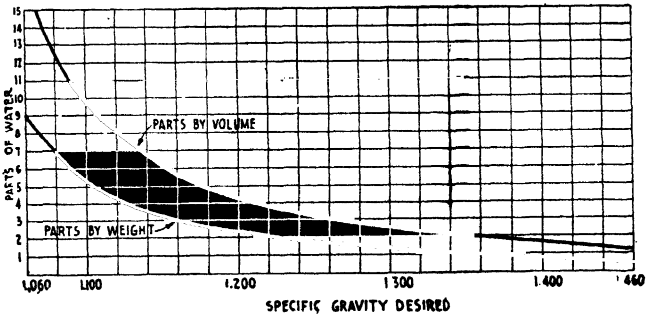


FIG. 1,773.—Curves for mixing full strength acid and water. Full strength or concentrated sulphuric acid is a heavy, oily liquid, having a strength (specific gravity) of about 1.835. If put into the battery, it would quickly ruin it, and must therefore *first* be diluted with pure (distilled) water to the proper strength for the particular type of battery, to which it is to be added. ***In mixing,*** take the following precautions: 1, Use a glass, china, earthenware, rubber or lead vessel; never metallic other than lead. 2, *Carefully pour the acid into the water;* ***not*** the water into the acid. 3, Stir thoroughly with a wooden paddle and allow to cool before taking a hydrometer reading. The electrolyte like most substances expands with rise in temperature; this affects the hydrometer reading. ***Correction for hydrometer reading;*** ***Add one point to hydrometer reading for every 3° Fahr. increase in temperature above*** 70°.

The use of low standard or impure electrolyte is a sure cause of battery trouble.

Do not confuse *chemically pure* sulphuric acid with sulphuric acid of full strength. For example, if a small quantity of some impurity be introduced into acid which is both chemically pure and of full strength, it would not materially reduce the strength, but would make it impure. On the other hand, if such acid be diluted by mixing with pure water it would still be pure, but its strength (specific gravity) would be reduced.

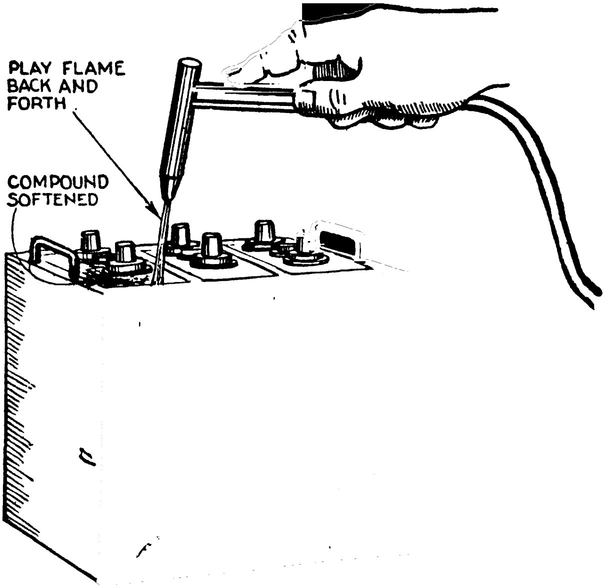


Fig. 1,774.—***Battery repairs 6.*** Soften the sealing compound around the edges of the covers by playing a gas or torch flame over the compound. It is best to play the flame back and forth and not steadily in one place.

Full strength or concentrated sulphuric acid is a heavy, oily liquid having a strength (specific gravity) of about 1.835. If put into the battery, it would quickly ruin it, and must therefore, first be diluted with suitable water to the proper strength for the particular type of battery to which it is to be added.

If electrolyte of the proper strength be not on hand, it may be prepared from chemically pure sulphuric acid by mixing the acid with pure water

The acid may be of any strength, provided it be stronger than the electrolyte desired, but it should be borne in mind that especial care must be taken in handling it when stronger than 1.400 and extreme care when it is stronger than 1.600. The proportions of acid and water depend upon the strength of the acid. Fig. 1,773 gives the proportions when the acid used is full strength or concentrated, which means a strength of 1.835.

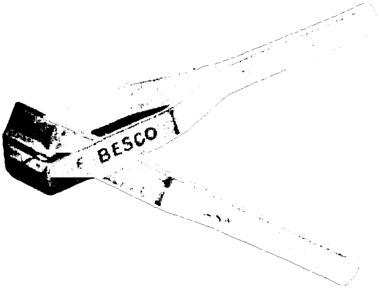


FIG. 1,775.—Besco end cutter for cutting off pillar posts to proper heights and trimming lead parts.

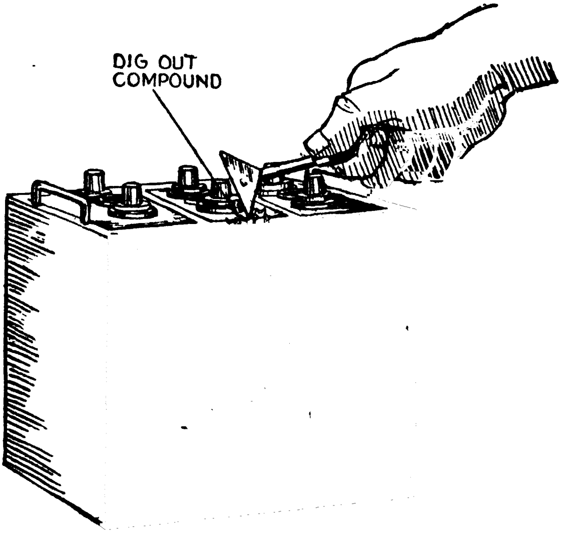


FIG. 1,776.—*Battery repairs 7.* Dig out the compound around the edges of the covers by using a heated screw driver, chisel or plumber's lead scraper.

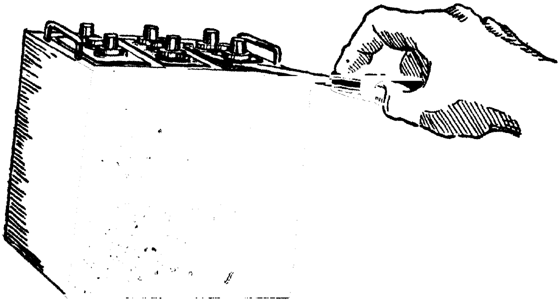


FIG. 1,777.—*Battery repairs 8.* Heat top of the covers to soften the underlying compound. Insert a screw driver under the covers and pry them off gently. Do not attempt to force them off but use more heat until they lift easily.

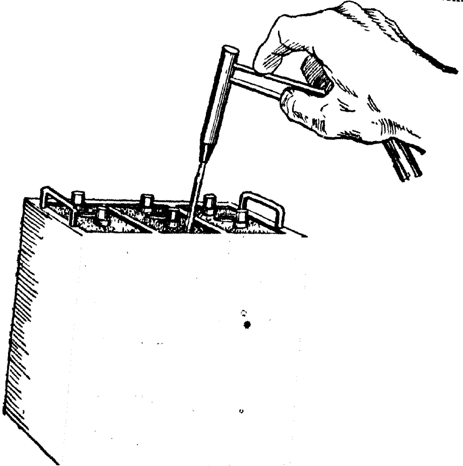


FIG. 1,778.—*Battery repairs 9.* Soften remaining compound with torch. Do not allow the flame to play in one place long as this would cause the compound to melt and run. A small flame used for several minutes will bring better results than a strong flame. After softening the compound it mav be removed by using a heated screw driver.

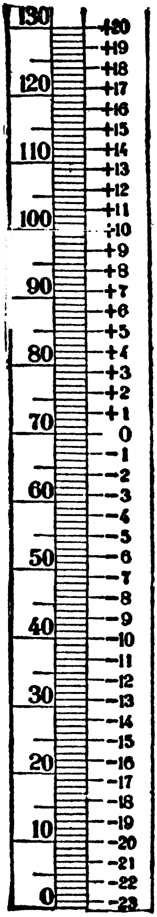
When mixing, take the following precautions:

1. Use a glass, china, earthenware or lead vessel; never metallic other than lead. Rubber may be used except when mixing acid of 1.600 gravity or stronger.

2. Carefully pour the acid into the water; *not* the water into the acid, as this might cause sputtering and therefore personal injury.

3. Stir thoroughly with a wooden paddle, and allow to cool before taking a hydrometer reading of the strength. If acid of 1.835 gravity be used, the wooden paddle should be coated with sheet lead.

Electrolyte, like most substances expands on heating, affecting the hydrometer reading. To compare different



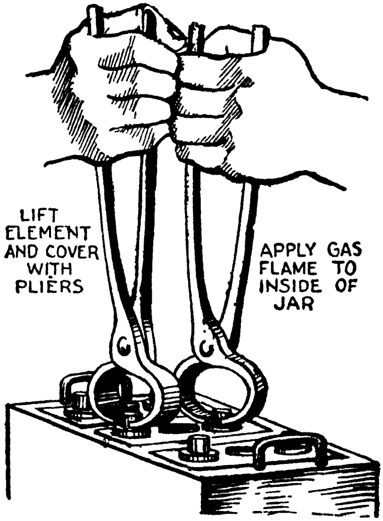

LIFT ELEMENT AND COVER WITH PLIERS
APPLY GAS FLAME TO INSIDE OF JAR

Fig. 1,779 —Fahrenheit scale. To correct specific gravity for temperature read thermometer to nearest + or − division. If +add to hydrometer reading. If − subtract. ***Example:*** thermometer 79 (correction + 3), hydrometer 1.209. Corrected gravity 1,209 + 3 = 1,212.

Fig. 1,780.—***Battery repairs 10.*** Apply the gas flame to the inside of the jar for an instant, then run a hot putty knife around the edges between jar and cover. Now place the battery on the floor and holding it firmly between the feet, grasp the terminal posts with two pairs of pliers and lift the element and cover out together.

hydrometer readings, therefore, the temperatures should be about the same. It is not necessary, however, to actually bring the temperatures to the same value, because it is a known fact that every 3 degrees increase in temperature decreases the hydrometer reading 1 point, and this fact can be used in estimating what the hydrometer reading would be at another temperature. For example, if the hydrometer reading at 95° be 1.275 it would be 15 points more, or 1.290 at 50°. Therefore, although the two actual readings differ by 15 points, the difference is all due to temperature, and if the temperature were the same the readings would be the same. When the temperature is much above or below normal, the hydrometer readings should be corrected for "temperature."

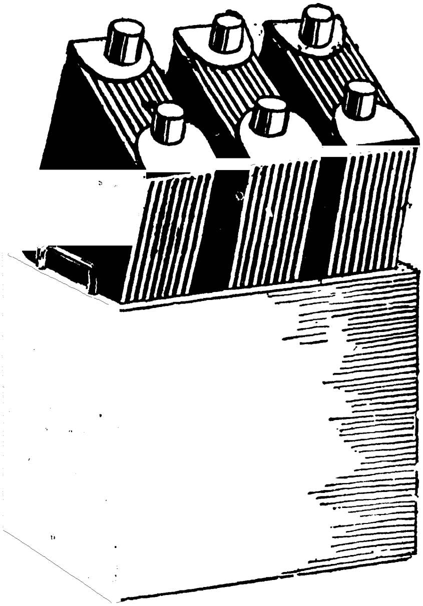


FIG. 1,781.—*Battery repairs 11.* Drain elements by resting them at an angle on top of jars While the elements are draining apply a flame around the terminal posts and remove covers The covers may have warped from the heat. If so, they should be placed in boiling water and flattened out on a smooth surface to cool.

In ordering sulphuric acid specify that it shall be chemically pure 1.835.

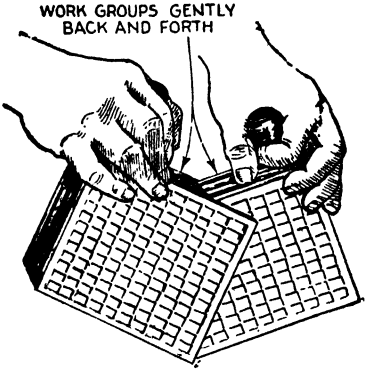

WORK GROUPS GENTLY BACK AND FORTH

FIG. 1,782.—***Battery repairs 12.*** If separators be in good condition, and a jar replacement only is to be made, set the element, with bottom cover, in electrolyte or water till ready to replace. If separation is to be renewed and plates examined, separate the positive and negative groups. Grasp the elements firmly and work the groups gently back and forth.

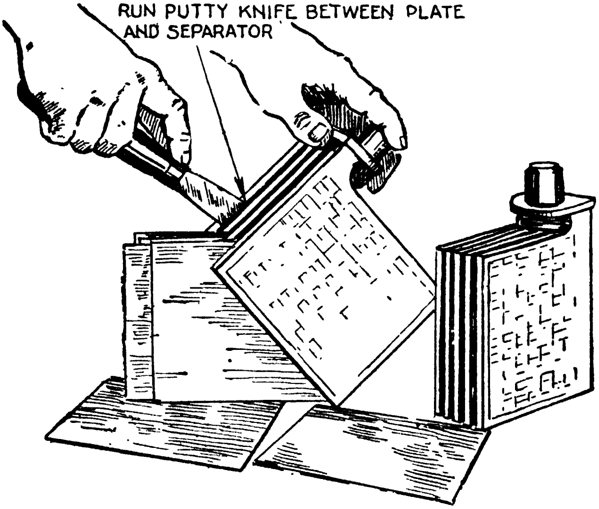

RUN PUTTY KNIFE BETWEEN PLATE AND SEPARATOR

FIG. 1,783.—***Battery repairs 13.*** Method of removing separators. Take a putty knife and run it between the plate and the separator. It is always best to renew the separators. When a new battery is received for replacement of a leaky jar the separators will generally be found in good condition so as not to require renewal. Used separators should never be allowed to dry out but should be kept immersed in water.

The readings should be taken at from 70° to 90° F. So called "commercial acid" is not satisfactory for use in storage batteries, and therefore, acid or electrolyte should be purchased from a storage battery company or a distributor. Inasmuch as the greatest density of electrolyte that should be put in the cells is 1.400, distributors carry electrolyte of this density.

When the battery is fully charged the electrolyte should show a specific gravity of 1.280 to 1.290.

For developing repaired cells with new positive and negative plates the initial electrolyte density should be 1.200.

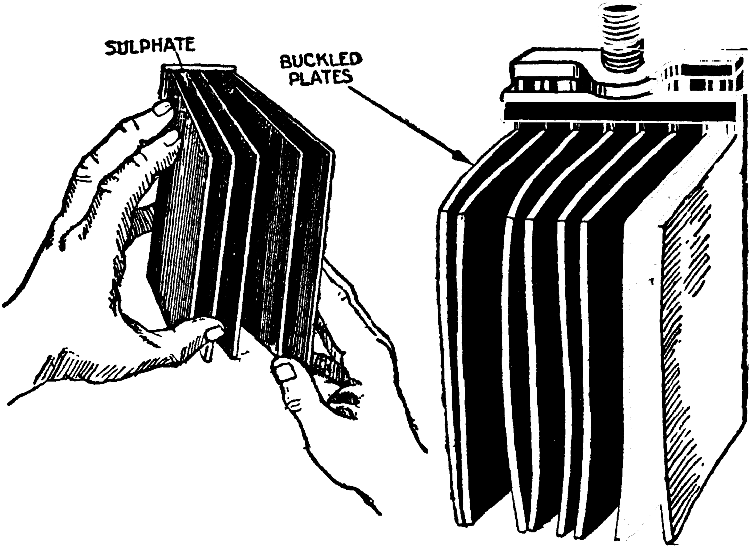


FIG. 1,784.—***Battery repairs 14.*** Inspection of plates to determine whether or not they require replacement. If battery has been overheated through overcharging or short circuiting this will be indicated by brittle and buckled plates with active material granular and falling away from the grid. Plates in this condition will have to be replaced. If electrolyte has not been kept above the plates the tops of the plates will show a white substance known as sulphate.

FIG. 1,785.—***Battery repairs 15.***—Positive group showing buckled plates. A group of buckled plates which, when reassembled, will not go into the jar readily, should be replaced with a new group.

NOTE.—*If the battery has been allowed to remain in a discharged condition* for any length of time it will be indicated by sulphated plates. This sulphation is susceptible to removal by charging at a low rate for a long period. This rate should be about one half the normal charging rate continued until the specific gravity and voltage reaches a maximum value.

For developing repaired cells with new positive and old negative plates that are in a charged, wet condition, the initial electrolyte density should be 1.250.

When wood separators only are replaced in a charged cell the initial electrolyte density should be 1.280°.

For developing batteries shipped "bone dry" special instructions are given on tag accompanying each battery.

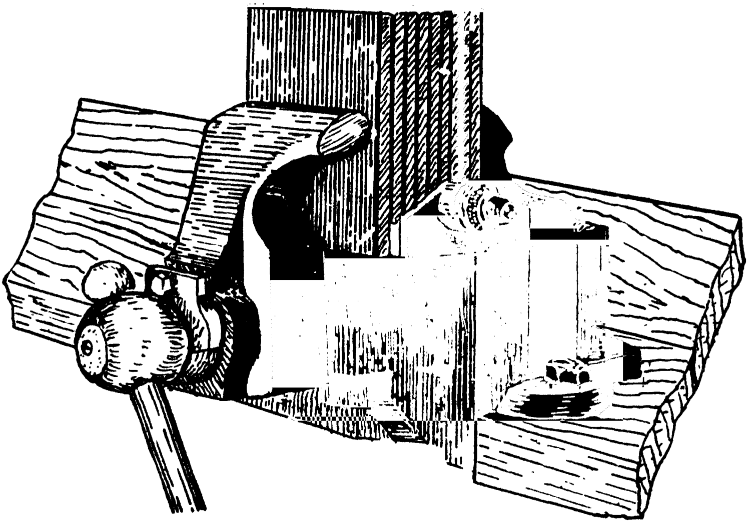


FIG. 1,786.—*Battery repairs 16.* Method of straightening buckled plates· Insert boards of suitable thickness between the plates and over each outside plate; place the pile in a vise, apply a gradual pressure, exercising care that the plates are not subjected to a severe strain.

To bring up the density of the electrolyte in a low cell the strength of the electrolyte added should not be greater than 1.400 or it may damage the plates and separators.

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*NOTE.—***The condition of the negative plates*** is sometimes such that they may be used again with new positives. In this case the negative group should be immersed in water to prevent the plates drying out through heating or exposure to the air. If the positive plate be fairly hard, and has not lost much of its surface, it may be used again. Occasionally it happens that one or two plates in a group require replacement while the balance of the plates are in good condition In this case new plates may be used in replacement.

Never add pure sulphuric acid to a cell, as it will gas and heat violently and will damage the plates and separators.

Table showing approximate number of parts of pure water to 10 parts of sulphuric acid (specific gravity 1.835) to prepare electrolyte of different densities.

READINGS AT 70° F.

Density	Parts by weight	Parts by volume
1.260	17.	30.
1.275	16.	28.
1.280	15.	27.
1.300	13½.	25.
1.400	8½.	15.8

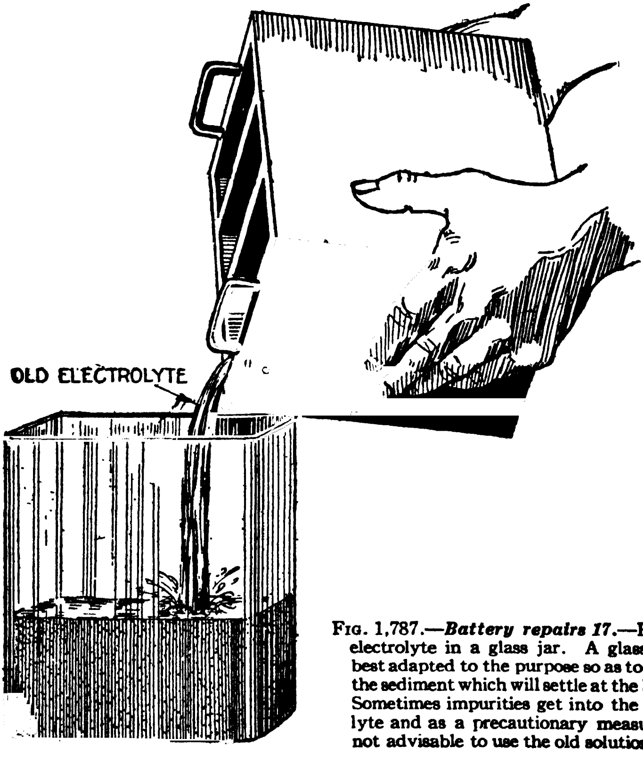


FIG. 1,787.—*Battery repairs 17.*—Pour old electrolyte in a glass jar. A glass jar is best adapted to the purpose so as to disclose the sediment which will settle at the bottom. Sometimes impurities get into the electrolyte and as a precautionary measure it is not advisable to use the old solution.

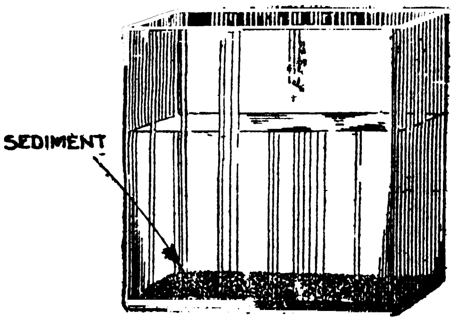


FIG 1,788 —***Battery repairs 18.***—Note the sediment which has settled at the bottom of the jar containing electrolyte Under normal usage this sediment will not be considerable. A large amount of it indicates that the cell has been overheated, and that the solution has not been kept above the plates by adding distilled water at regular intervals

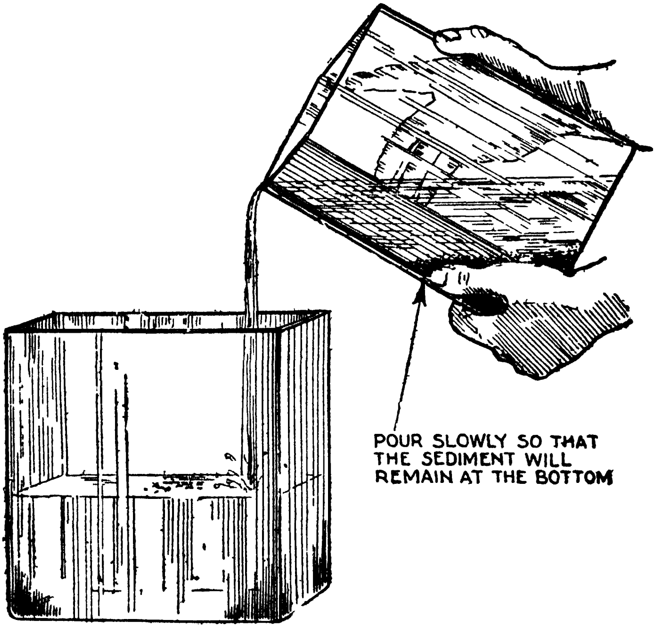


FIG. 1,789 —***Battery repairs 19.***—Pour off clear electrolyte. Never allow the sediment to get into the battery as it would impair the efficiency of the separators.

Ques. What may be said with respect to impurities in the electrolyte?

Ans. The electrolyte should be free from chlorine, nitrates, acetates, iron, copper, arsenic, mercury, and the slightest trace of platinum.

Mercury alone has no injurious effect unless it be present in sufficient quantity to amalgamate the plates, but in combination with any other metal, may cause local action.

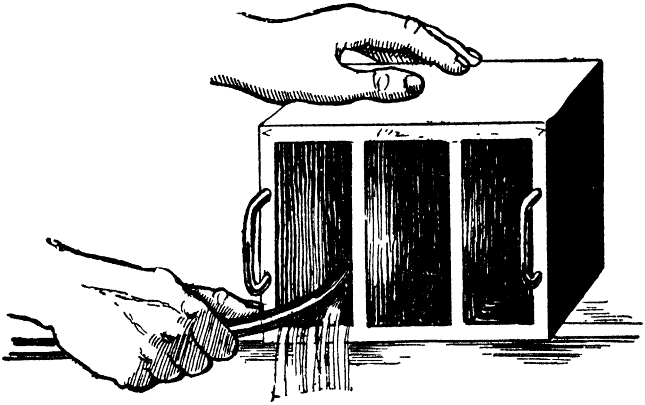


FIG. 1,790.—*Battery repairs 20.* Wash out jars with a water hose The case is placed on its side over a sink as shown and thoroughly washed out. Be sure that all sediment and foreign matter is removed from the cells before installing the plates.

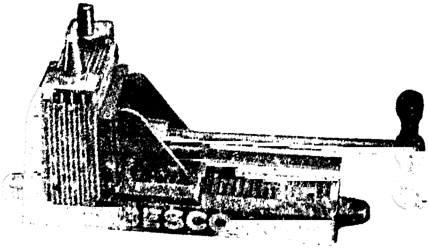


FIG. 1,791.—Besco battery vise and plate press. Serves a double purpose. As a battery vise it clamps the battery firmly without injury, making it easy to extract groups, cells or rubber jars. As a plate press it assures a steady graduated pressure so essential in straightening buckled plates or pressing groups back into shape to fit jars. Can be bolted to floor or bench

The following tests should be made for impurities before the electrolyte is poured into the cells:

Chlorine.—To a small sample of the electrolyte add a few drops of silver solution (20 grains of silver dissolved in 1,000 cu. cm. of water). A white precipitate indicates chlorine.

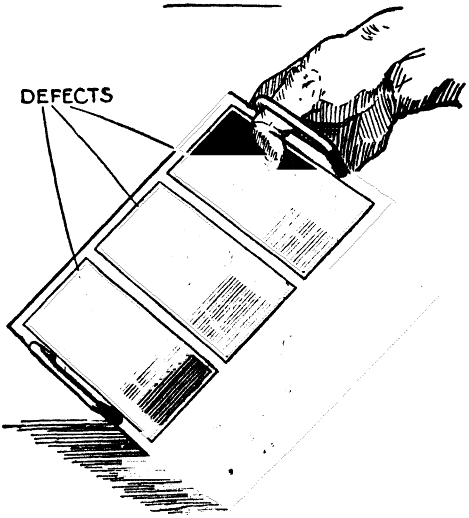


FIG. 1,792 —*Battery repairs 21.* Clean case ready for assembling of elements. Inspect the jars carefully for cracks or other imperfections. Jars exhibiting such defects should be replaced with new ones.

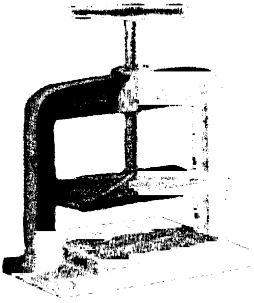


FIG. 1,793 —Battery plate press. ***It is made*** for straightening and forcing of active materials back into the grids This plate press is made of cast iron and reinforced to withstand the necessary pressure. A great amount of force can be applied easily and quickly.

Nitrates.—Place some of the electrolyte in a test tube, and add 10 grains of strong ferrous sulphate solution. Carefully pour down the side of the test tube a small amount of chemically pure concentrated sulphuric acid. A brown stratum between the electrolyte and the concentrated acid indicates the presence of nitric acid.

Acetic Acid.—Neutralize the electrolyte with ammonia, then add ferric chloride. If the solution turn red, and is afterwards bleached by the addition of hydrochloric acid, acetic acid is present.

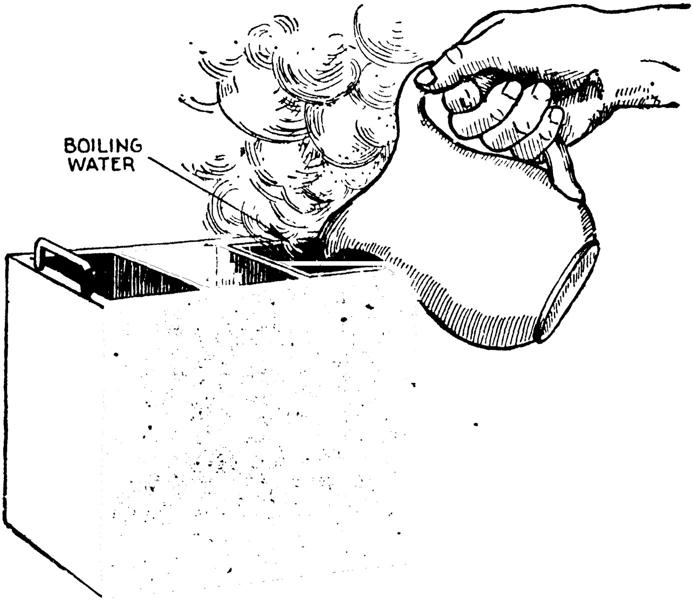


FIG. 1,794.—***Battery repairs 22.*** To remove a jar fill it with boiling water and allow it to stand for at least five minutes. This will loosen the sealing compound surrounding the jar.

Iron.—Neutralize a sample of the electrolyte with ammonia; boil a small portion of hydrogen peroxide, and add ammonia or caustic potash solution until the mixture becomes alkaline. If a brownish red precipitate form, it indicates iron.

Copper.—If copper be present, a bluish white precipitate will be formed when ammonia solution is added to the electrolyte.

Mercury.—This is indicated by an olive green precipitate when a solution of potassium iodide is added to the electrolyte, or by a black precipitate when lime water is added.

Platinum.—A rough test for traces of platinum is made by pouring the electrolyte into a cell in which the battery plates are immersed. If gassing take place for some time on open circuit, it is an indication of the presence of platinum.

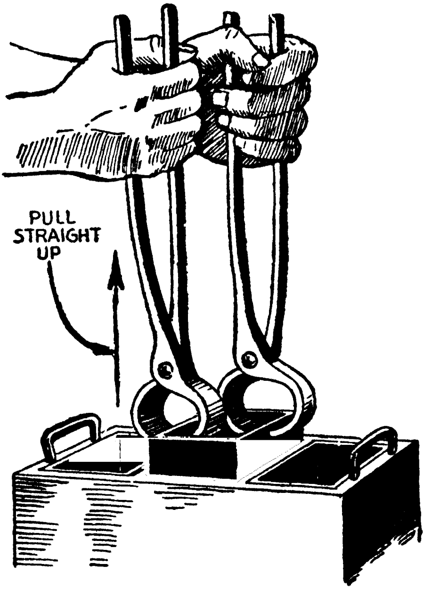


Fig. 1,795.—*Battery repairs 23.* Grasp the edges of the jar to be removed with two pairs of pliers as illustrated and pull it straight up. Care should be exercised so as not to damage adjacent jars.

Table showing approximate number of parts of pure water to 10 parts electrolyte (1.400 spec. gravity), to prepare electrolyte of different densities.

READINGS AT 70° F.

Density	Parts by weight	Parts by volume
1.260	4.7	6½
1.275	4.	6.
1.280	4.	5½
1.300	3.	4¼

Specific Gravity of Electrolyte in Tropical Countries.—The electrolyte used in automobile batteries in tropical climates is purposely made weaker because such batteries operated in tropical climates give better results if the solution be weaker than that used in batteries for cooler climates.

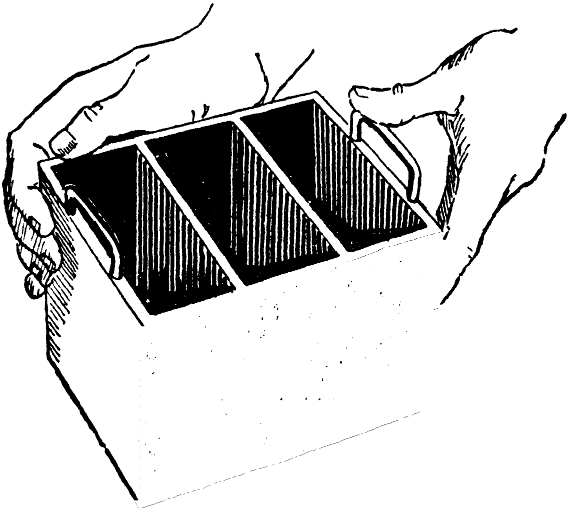


FIG 1,796—*Battery repairs 24.* Inspection of case before putting in new jars. Remove the shims and sealing compound so as not to hinder the jars from being placed properly

Places where freezing of water seldom or never occurs are regarded as having tropical climates In countries where the average temperature is around 100° or more throughout the year, it is recommended that the specific gravity of a fully charged battery be kept at about 1 280 ordinarily used This is due to the fact that with the increase of temperature, the specific gravity of electrolyte decreases, the ratio being that for each 3° increase of temperature, there is a decrease of one point in specific gravity This means that when the temperature has been increased 30° the gravity actually reading on the hydrometer would be 10 points less than it would be if the temperature were normal

In this way, if the standard specific gravity (1 280) were used, the actual specific gravity of a battery in hot climates would be from 10 to 25 points too high, with the result that the battery would be wearing out faster.

Installation of Batteries.—When installing a new battery the following precautions should be taken:

1. Battery compartments must be well ventilated, but in such a way as to keep out water, oil, dirt, etc. Install battery so that all cells are easily accessible for adding the water necessary to replace loss from evaporation.

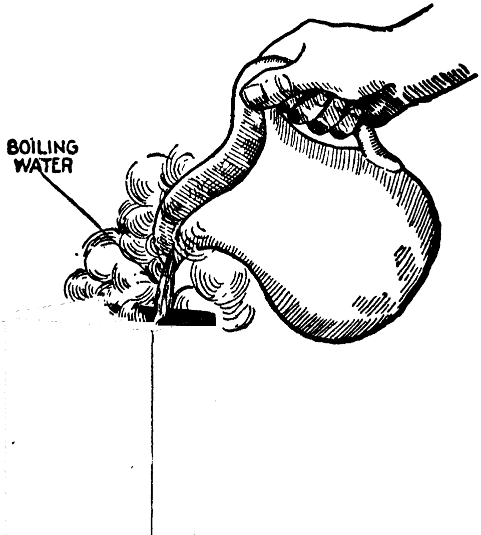


FIG. 1,797.—***Battery repairs 25.*** Heat jar before placing it in the case. This may be accomplished by pouring boiling water in the jar. If hot water be not available play a light flame around the outside of the jar.

2. Arrange connections so that positive of charging source will connect with positive of battery, and negative of charging source with negative of battery. Test charging wires for positive and negative with a volt meter, or dip the ends of the wires in a glass of salt water, but do not allow ends of wires to touch. In the water, fine colorless bubbles will be given off from the negative wire.

3. Before making connections all surfaces which are to be bolted together should be wiped with a cloth wet with ammonia, thoroughly scraped and then coated with pure vaseline. The metal is apt to be covered with a very thin film of acid and unless this be neutralized and removed before making connections, there may be trouble from corrosion later.

4. Batteries in service on vehicles of any sort should have the trays seated firmly and evenly without any undue twisting or straining and should be securely fastened down by suitable holding devices, so designed that they will not shake loose in service. Connecting cables must be flexible and sufficiently long to prevent a pull on the battery terminals.

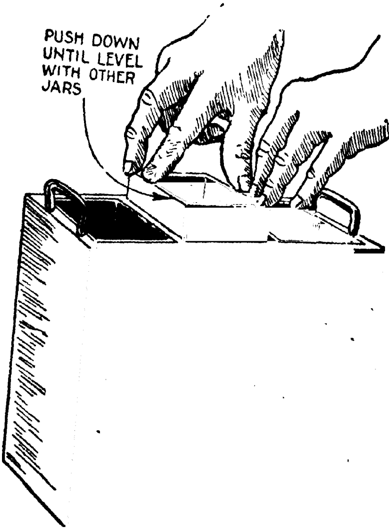


Fig. 1,798.—***Battery repairs 26.*** Push jar into place, taking care to see that the top of the jar is level with the others. If the tops be not lined up, the top connectors will be uneven, and as a result present a very poor looking job.

5. It is absolutely essential that the battery be securely held in position on the car, and for this purpose "hold downs" have been developed. The simplest form of hold down consists of a bolt fastened to the car and which grips the case by means of a clip fitting the case handle.

6. If a battery be allowed to jump around in its compartment, the result is unnecessary wear or breakage or both. The ribs in the bottom of the jars may wear grooves into the plates and separators or the plates may wear grooves into the ribs. Battery terminal posts are sometimes broken as the result of a loose battery straining on a connecting cable which has become taut as a result of the battery moving.

7. Always see that the battery is fastened securely in place by means of holding devices.

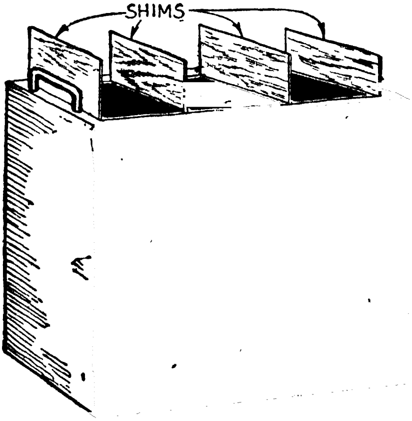


FIG. 1,799.—*Battery repairs 27.* Place a paraffined wood veneer shim between the jars to secure a proper spacing and a tight fit.

To Install New Battery on Car.—See that the positive and negative terminals of the new battery are in the same position as those on the one it is to replace. This is of importance, especially when the car is equipped with an electric starting and lighting system.

Six volt batteries have one positive and one negative terminal.

Batteries used on 12, 16, 18 and 24 volt systems often have a greater number; and different systems have these terminals located in different positions.

If the connections be not made correctly the starting and lighting system will not operate properly, and if the terminals of the new battery be not in the same position as those on the battery to be replaced, the wiring must be changed to fit the new battery. Usually the polarity of each terminal is stamped thereon, but as an extra precaution this should be checked with the volt meter.

Rub connections and terminals with sand paper until they are clean and bright. Go over them with a rag dampened with ammoniated water (one part ammonia, ten parts water) and screw connectors tight to the terminals. Coat the terminals and connectors with vaseline or heavy grease.

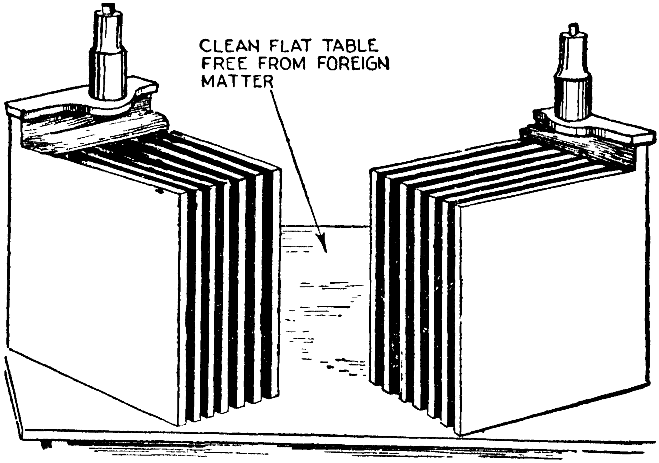


FIG. 1,800.—*Battery repairs 28.* First step in replacing elements. Take the positive and negative groups to a clean, flat table. Always make sure that the work table is free from lead scrapings or foreign substances of any kind as these substances will adhere to wet separators, and if not removed will cause short circuiting of the plates.

Be careful that the battery hold downs or other devices for keeping the battery in place are suitable for the new battery.

If the car be equipped with a starting and lighting system have the owner operate the engine; first, to see that the battery revolves the starting motor, and, second, to see that the battery receives the proper charge when engine is running.

Battery Storage.—Batteries which have electrolyte in the cells, must during the idle period, be kept charged, have water added as necessary, and not allowed to become extremely hot or extremely cold. The question usually arises whether it is better to dismantle the battery and store it *dry* or put it into storage as it is, this being termed *wet* storage.

Any battery which is to be out of commission should, if possible, be put into wet storage, provided it will not soon require dismantling, in which case it should be put into *dry* storage. *Dry* storage requires no attention during the storage period. The battery must, however, be dismantled and reassembled, and if its condition be such that this will soon be required anyway, dry storage is obviously the better method.

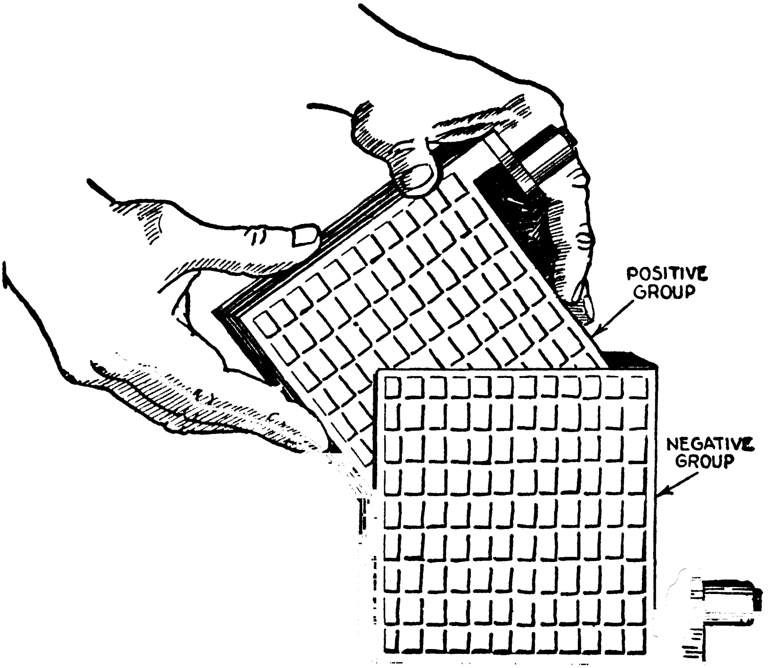


FIG. 1,801.—***Battery repairs 29.*** Second step in replacing elements. Intermesh the positive and negative group. As the negative group contains one more plate than does the positive, both outside plates will be negative.

Dry Storage.

1. Provide a dry place for storage, free from dust.

2. Have on hand enough approved water to fill all the cells.

3. Empty the battery solution by tilting and turning over the battery and immediately replace the solution with the water.

4. Allow the battery to stand filled with water for approximately 10 to 15 hours.

5. Give the battery a charge, continuing until *all* cells gas freely and until half hourly readings of the specific gravity of any certain cell and of the voltage of the battery as a whole both show no further increase over a period of 1 hour.

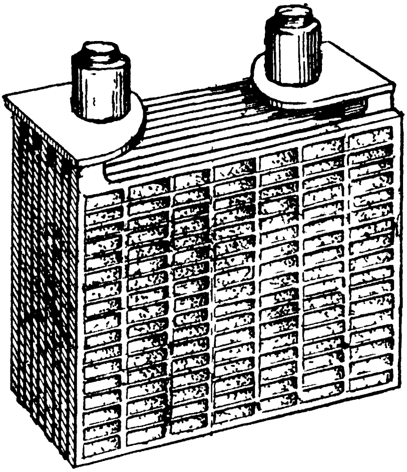


FIG. 1,802.—***Battery repairs 30.*** Complete element ready to receive separators.

6. Unseal the cells and pull out of the jars the elements complete with covers; that is, without removing sealing nuts.

7. Remove the separators.

8. Wash the plates by dipping them several times in water.

9. Replace the separators, using new ones for the wood separators. Be sure these are thoroughly saturated. Where there are rubber separators, they may be used again, if they are not broken or cracked.

10. Pour the water out of the jars

11. Put the elements back into the jars and reseal before the negatives dry out.

12. Put a tag on each battery, giving the date put into storage.

13. Replace and tighten vent plugs.

14. Within 12 months put the battery into service. It is preferable to do this immediately and then keep in wet storage on *trickle charge*.

15. If it be impossible to reseal the cells, as covered in item 11, proceed as in items No. 1 to No. 6, inclusive. Then remove the wood separators and throw them away. Where there are rubber separators, replace them between the plates. Allow the plates to drain and thoroughly dry. Pour the water out of the jars. Put the elements back into the jars, but do not seal.

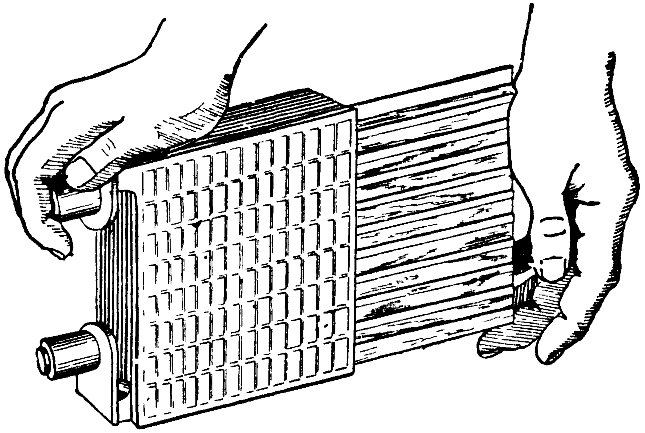


FIG. 1,803.—***Battery repairs 31.*** Method of inserting separator. Lay the element on its side and put the separator retainers in position. Insert a separator between each pair of plates. If wood separators only be used, the grooved side of the separator should be next to the positive side. If wood separators and rubber sheets be used, they should be inserted together, the rubber sheet between the positive plate and the grooved side of the wood separator. See that the separators are against the retainers and that they extend equally on either side of the element Carefully check up separators after assembling as to omit a separator would cause considerable trouble possibly spoiling the cell.

Wet Storage.

1. Provide a bench or shelf in a convenient location and of sufficient size to allow a little air space all around each battery.

2. Place the batteries upon wood strips, in order to keep the bottom of the batteries clear of the bench.

3. Install the necessary wiring, switches and charging resistance, so that batteries can be easily connected up and charged where they stand on the bench.

4. Apply vaseline freely to all exposed metal other than lead.

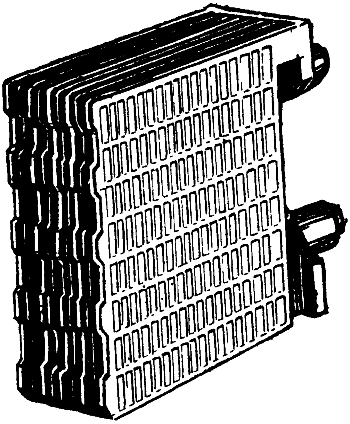
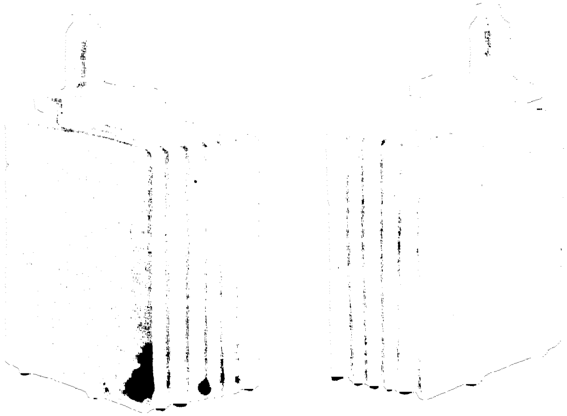


FIG. 1,804.—***Battery repairs 32.*** Complete element. The element should be grasped by pillar post and lowered gently into the jar. This should be done very carefully to avoid breaking the jar.



FIGS. 1,805 and 1,806.—Willard positive and negative groups of plates. Fig. 1,805 negative group; fig. 1,806, positive group.

5. Batteries may be kept in wet storage by means of either the trickle charge or periodic charge method.

Battery Testing in the Car.—If the battery be in a car it

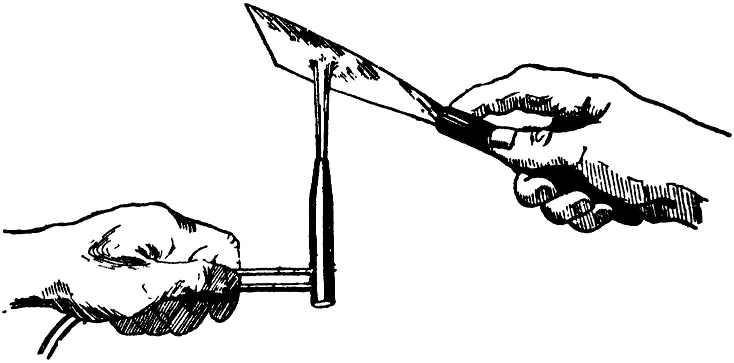
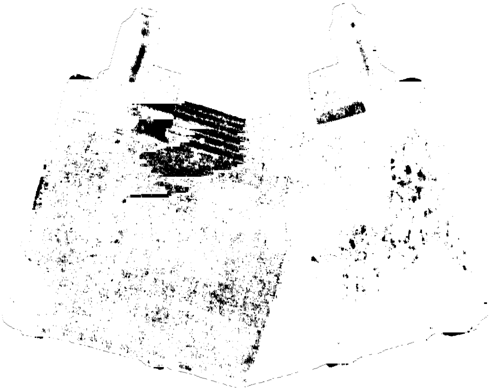


Fig. 1,807.—*Battery repairs 33.* Method of heating putty knife with torch preparatory to cleaning the covers.



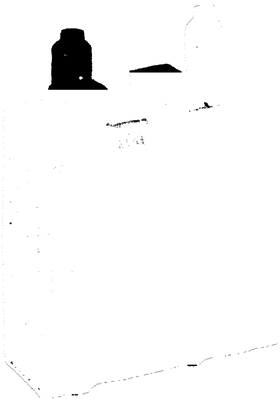


Fig. 1,808.—Willard positive and negative groups being assembled.

Fig. 1,809.—Willard element or assembly of positive and negative plate groups with separators

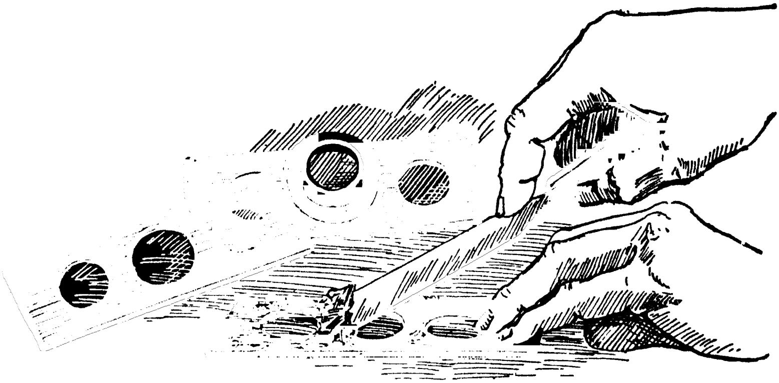


Fig. 1,810.—***Battery repairs 34.*** Clean covers with heated putty knife.

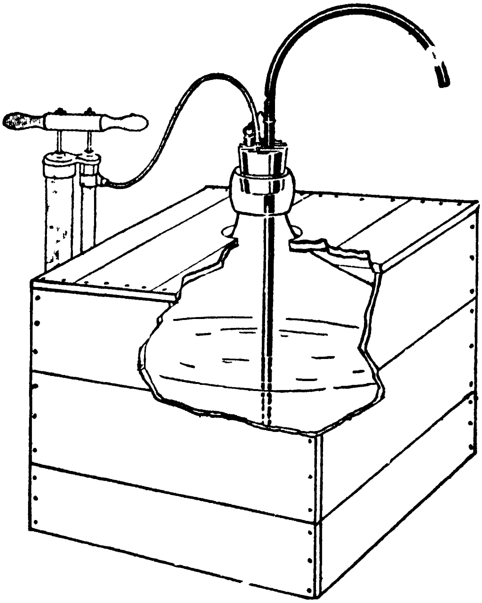


Fig. 1,811.—Adaptation of auto tire pump as an acid pump The lead pipe can be adjusted to reach bottom of deepest carboy. Any auto or bicycle air pump can be used with it.

should be tested with the hydrometer to determine the state of the charge of the cells, and to determine if the density of the solution in the cells be uniform.

The height of the solution should also be determined, and if not at the proper height, the cell should be replenished with pure water. If no trouble be indicated, see that the case is clean, wiping with ammonia solution, one part ammonia and ten parts water. See that the terminals are tight and that the battery is held rigidly in the battery box.

If the test show the level in one cell lower than in the others, it is indicative of a leak or that acid has been spilled from this cell.

If one cell be markedly low in gravity, or if owner complain that he has to fill one cell more frequently than the others a leak or spilling as just mentioned, is also indicated. A leaky cell should be repaired at once.

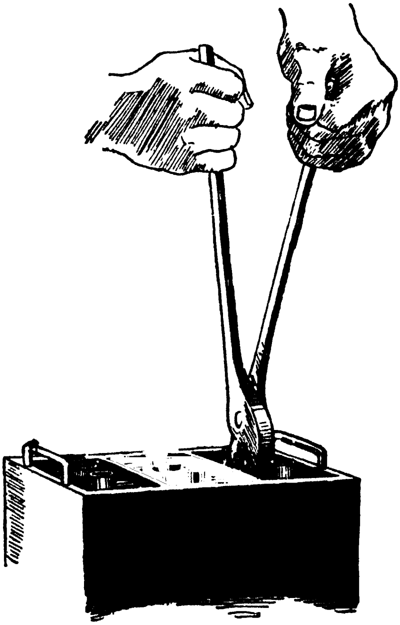
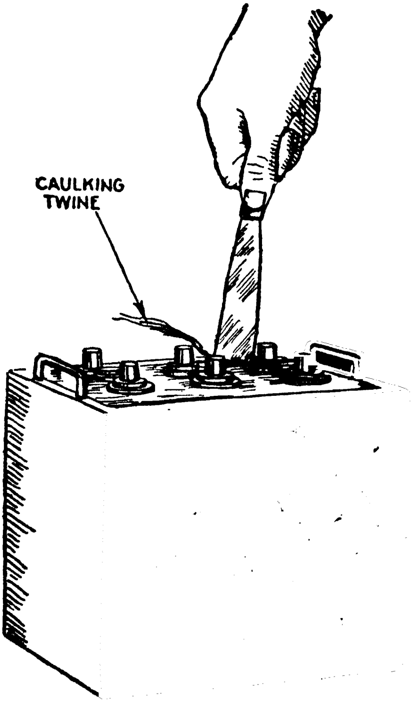


FIG. 1,812.—***Battery repairs 35.*** Sometimes the bottom cover will not fit properly over the element. By using a pair of pliers in the manner illustrated, it will be an easy matter to locate the centers.

If on the other hand, low acid level or low gravity be due to spilling, the battery should be charged and acid density adjusted.

If, however, the test show that all of the cells are in completely discharged condition, or the owner complain that he is unable to keep the battery charged, the wiring and starting system should be checked as follows:



1. Point of dynamo cut in, also the speed of the car at which the dynamo commences to give the battery its normal charge. Dynamo systems are designed to give this charge at about 12 miles per hour, and if the dynamo do not, it is probable that the battery is not receiving sufficient charge.

It may be that the commutator is dirty or is covered with oil from the dynamo bearings. In this case the resistance between the commutator and brushes may prevent the dynamo charging the battery at the proper rate. The commutator should be carefully examined and if found to be dirty should be cleaned with sand paper.

2. If the cut out switch be not working properly the battery will discharge back into the dynamo, thus losing power.

FIG 1,813—***Battery repairs 36.*** **If the cover do not fit closely to the terminal posts, or the wall of the jar, the openings should be calked with hemp twine or tow to prevent the melted sealing compound flowing into the jar**

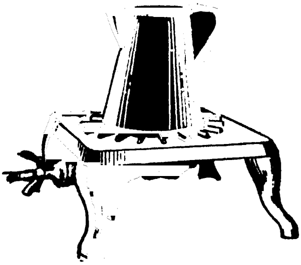


FIG. 1,814.—***Battery repairs 37.*** Small gas stove and ordinary coffee pot used for melting and pouring sealing compound.

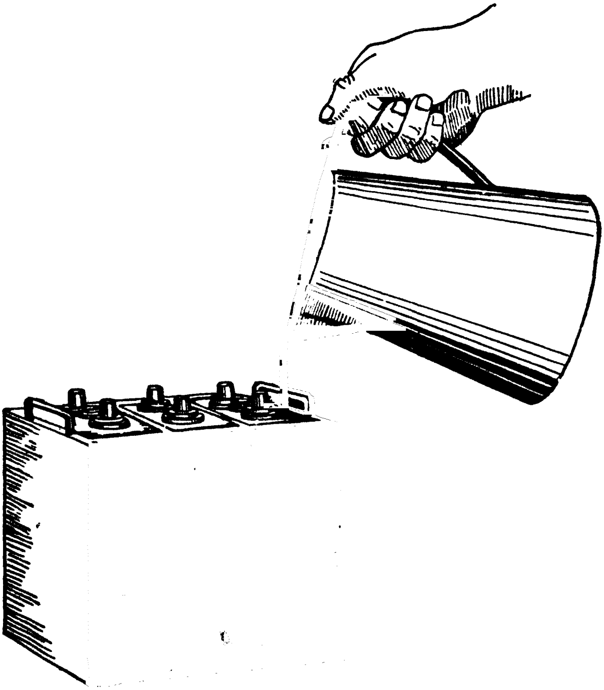


FIG. 1,815.—***Battery repairs 38.*** Application of compound. Always pour the compound so that it will fill all spaces and reach to a height level with the top of the case. Also see that it flows evenly over the whole surface.

3. The wiring may be accidentally grounded to the metal frame work of the car, in which case there will be a continual leak from the battery. If the car be wired on a single wire system, in which one side of the battery is intentionally grounded, break this grounded connection and shut off the lights and the ignition. Then test with the volt meter, connecting one post to a battery terminal, the other to the metal frame work of the car. This test should be made with all terminals. If the volt meter show a reading it indicates a ground in the wiring. When the wiring is on the double wire system it is not necessary to break any connections.

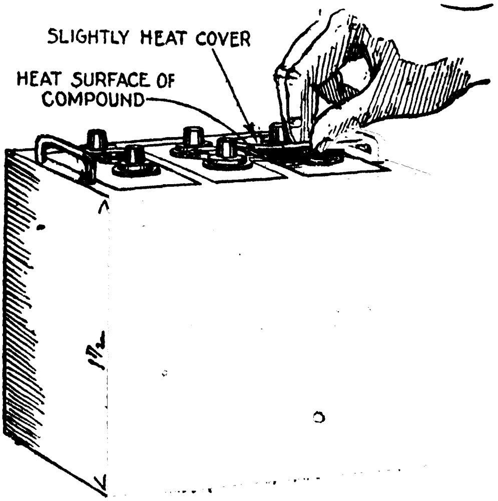


Fig. 1,816.—*Battery repairs 39.* Before putting on the cover slightly heat it with a gas flame. Also heat the surface of the compound.

If a ground exist it should be cleared up before the battery is put back in service.

4. The user may operate a great deal at night and little in the day time. or he may drive in a congested district at slow speed, or he may make frequent stops. Any of these may prevent the battery receiving sufficient charge, and under these circumstances the user should be instructed to use his lights as sparingly as possible and only to use the headlights when absolutely necessary. In some cases side and tail lights of lower candle power than used on the car may remedy the condition.

If none of these precautions will allow the battery to receive sufficient charge, it should be given a recharge periodically at a service station.

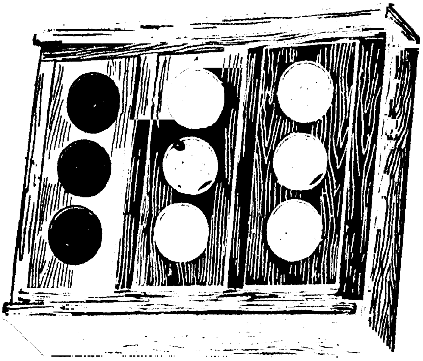


FIG. 1,817.—*Battery repairs 40.* Wooden form used for properly holding the covers down while the compound is cooling.

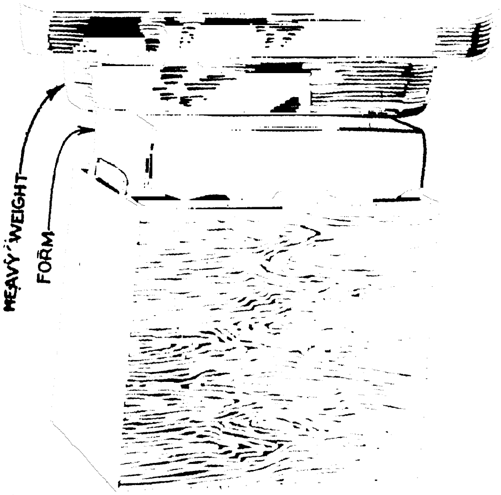


FIG. 1,818.—*Battery repairs 41.* Place the wooden form over the covers and place a heavy weight on top of the form. The battery should stand for ten or fifteen minutes until the sealing compound has set.

For the foregoing tests on the starting system, a small ammeter and volt meter may be used; it is advisable, however, to have a combination instrument especially designed for automobile testing work, of which a number are on the market.

As various starting systems differ materially in operation, it will be well to apply to the manufacturers of these systems for diagrams and instructions.

5. A frequent source of battery trouble is loose or corroded connections at the battery or at the dynamo. In either case the battery will not receive the proper current on charge or give it out on discharge. All connections should, therefore, be examined carefully to see that they are clean and tight.

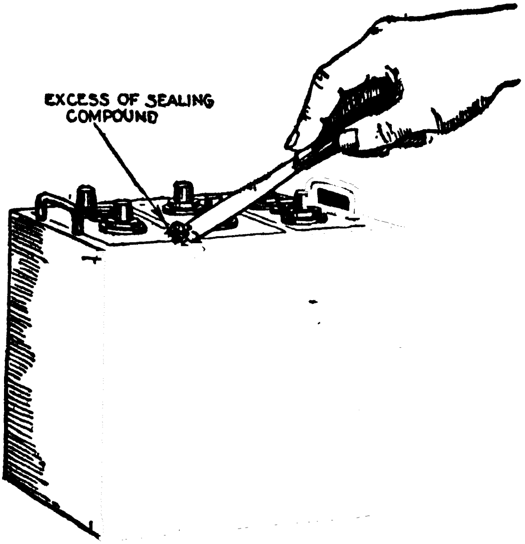


FIG. 1,819.—*Battery repairs 42.* After the form is removed there is always an excess of sealing compound. This can be scraped off with a hot putty knife.

Testing Battery Removed from Car.—If trouble exist that is clearly due to the battery or if test on the starting system fail to clear the difficulty, the battery should be removed from the car for repair or replacement.

Battery Troubles.—In order to locate the faults in battery troubles:

1. Go over all connections in the system. A loose or dirty connection is often the cause of trouble. If the connections between battery and cable terminals be not kept clean, they may corrode, causing a poor connection, or else opening the circuit altogether. If the connector be causing the trouble, remove it and clean the parts thoroughly with weak ammonia. Then remove all dirt, apply vaseline, tighten the connections perfectly and give the whole connection a heavy coating of vaseline.

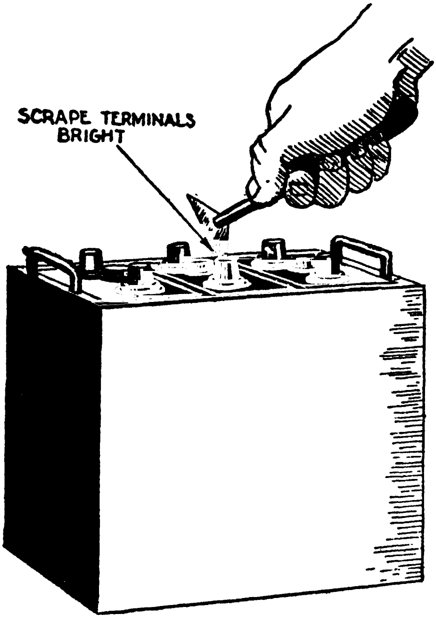


Fig. 1,820.—*Battery repairs 43.* Terminals should be thoroughly scraped clean of all compound and dirt. It is practically impossible to do a good job of burning if all parts be not properly cleaned.

There may be a leak or ground in the wiring. Test for this by turning on all lamp switches and then removing the bulbs from the sockets. Disconnect one of the cables at the battery and in its place tightly hold a file against the battery post, making sure there is good electrical contact between the file and post. Then rub the cable terminal along the file; if sparks be noticed, there is a ground in the wiring, which must be looked for and removed.

3. For an automobile battery:

a. If engine will not crank, turn on lights and attempt to start in the usual manner. If lights become dim, battery is in poor condition and should be given a charge off the car and the cause of trouble investigated and removed. If lights continue to burn brightly, the trouble is elsewhere than in the battery.

b. If the dynamo of the starting system be not in proper adjustment, the battery will not be kept supplied with the proper amount of current.

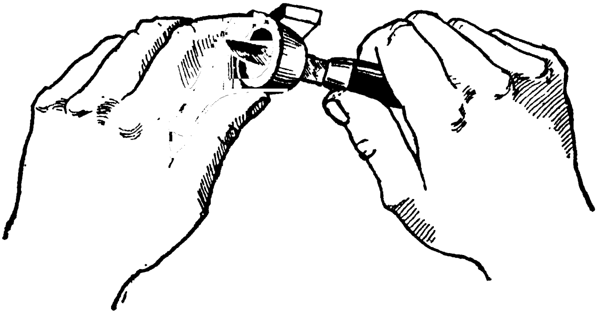


FIG. 1,821.—***Battery repairs 44.*** Method of cleaning the inside of connectors with ordinary pocket knife.

If the supply be insufficient, the battery will become discharged; if it be too much, the battery will require an excessive amount of water and the solution will become hot (110° Fahr.). The dynamo should be readjusted to deliver more or less current, as the case may require. On all cars, the dynamo is originally adjusted to supply an amount of current which experience has shown to be the most satisfactory for average running conditions. If the car be run only at night, more current is naturally required because the lights use a large part of the current which would otherwise go to the battery. If long daylight runs be the rule, the opposite is true because then almost all the current goes into the battery.

4. If the trouble seem to be in the battery, proceed as directed in the next section.

How to Determine the Necessity for Opening Cells.—If a battery seem to be in trouble and the cause be not apparent, it may require nothing more than prolonged charging to restore it to normal condition.

To determine what is necessary to restore it, first take a gravity reading of each cell and if practicable, make either the high rate discharge test, or, if the modified constant voltage system or charging be used, the high rate charge test.

If there be not enough electrolyte to float the hydrometer, add water and put the battery on charge, continuing until the water is thoroughly mixed by gassing, then take hydrometer readings.

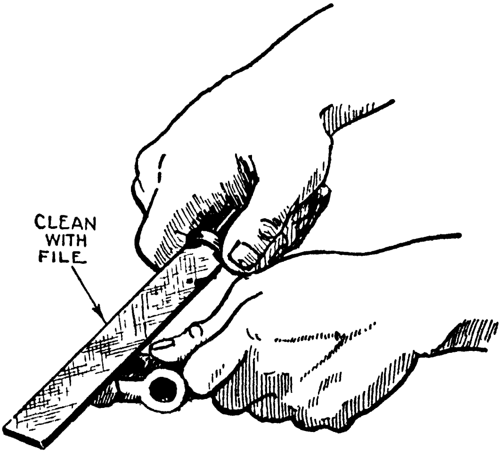


Fig. 1,822.—*Battery repairs* 5. Clean the tops of the connectors with a rasp file to remove dirt and oxide.

If the gravity readings of all cells be within 50 points of each other, most likely all the battery needs is a charge with a possible gravity adjustment.

If the gravity reading of one cell differ from the others by 50 points or more:

NOTE.—*Before applying the terminal connectors,* test all cells with a volt meter to see if they be set up properly. If a volt meter is not handy scrape the rubber bushings on each post. The red bushing is positive and the black is negative. The connectors should be applied so that the positive of one cell is connected to the negative of the next cell.

a. Make the high rate discharge test and be guided by its indications; or

b. If the constant voltage system of charging be used, make the high rate charge test and be guided by its indications; or

c. Put the battery on charge.

If all the cells gas evenly on the charge and the gravity of all of them reach and remain between reasonable limits, the trouble is elsewhere than in the battery. Locate the cause of trouble and remove it. Otherwise, record all gravities outside of these limits, resume charge and continue until three consecutive half-hourlv readings of the gravity of all these cells

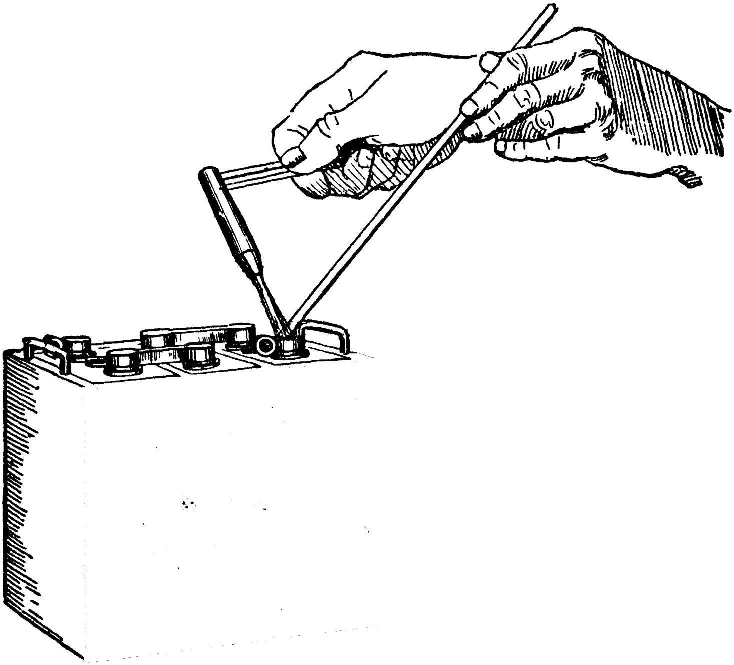


FIG 1,823 —***Battery repairs 46.*** Joining connectors and terminals to the posts. Melt the top of the post, then the edges of the hole in the connector. Melt strips of antimonious lead and allow the molten metal to run into the hole in the connector Care must be taken to see that the top of post and inside edges of the connector are melted together before applying additional lead. If this be not done the connection will surely pull loose Care should also be taken not to melt the outer edges of the connector Practice will be found necessary.

show no increase for any of them. Then make a gravity adjustment on those which are more than 10 points low or which are more than 10 points high and which are gassing. Before making an adjustment for low gravity, determine whether the jar be cracked by adding water to the proper height and allowing cell or jar to stand several hours, noting whether level falls. If a jar be cracked, change it. *Never make a gravity adjustment on a cell which does not gas.* If a cell will not gas on above charging, investigate for impurities, or inspect it for short circuits.

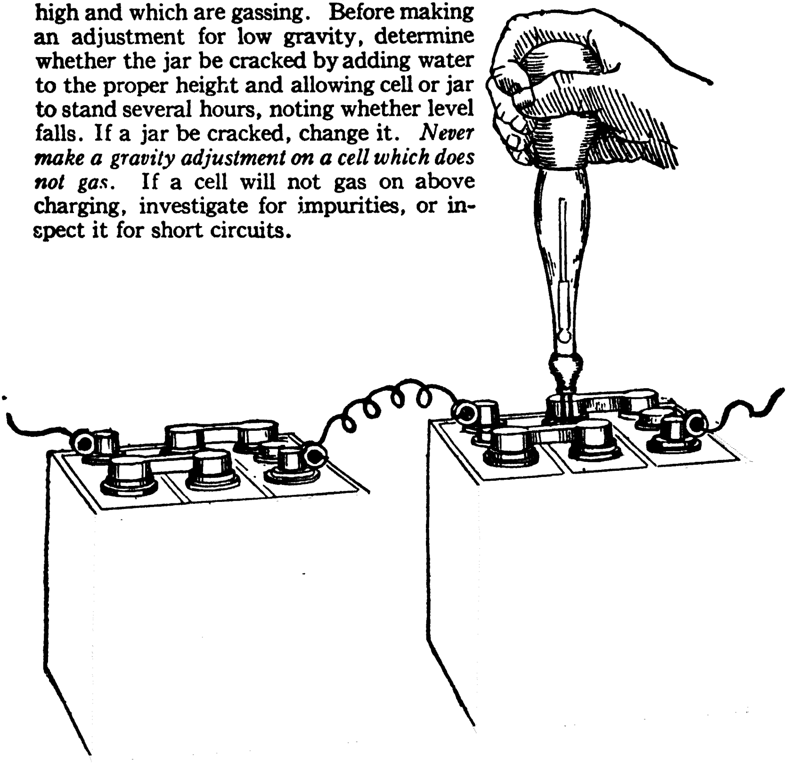


FIG. 1,824.—***Battery repairs 47.*** Testing electrolyte to note condition of charge.

NOTE.—***How to adjust the gravity.*** ***First make sure charging will not raise the gravity.*** To do this, continue a charge until the specific gravity shows no rise, and then for 5 more hours. ***Never make a gravity adjustment on a cell which does not gas on charge.*** Make an internal inspection to locate the trouble. ***To adjust low gravity,*** first have ready sufficient electrolyte of not over 1 345 specific gravity. Empty the solution out of the cell or cells and at once fill with the prepared electrolyte. Do not allow the battery to remain empty. Charge until all cells have been gassing for an hour. Then, if the gravity be not within proper limits for the type of battery being treated, repeat adjustment until desired gravity is obtained. ***To adjust high gravity,*** remove some of the electrolyte and replace with water. Charge until all cells have been gassing for an hour. Then, if the gravity be not within proper limits, repeat adjustment until desired gravity is obtained.

Lead Burning.—Lead joints in a battery are made by melting the parts to be joined and forming a solid weld. The process is called *lead burning*, and is carried out by means of a burning outfit. For a repair station, the use of gas is recommended. Where burning must be done on a job away from the station, the carbon burning outfit is recommended because it is easy to carry.

Various Gas Combinations.—There are various good combinations, and the deciding factor is usually the relative cost and availability of the different gases in the particular location in question. Good combinations are:

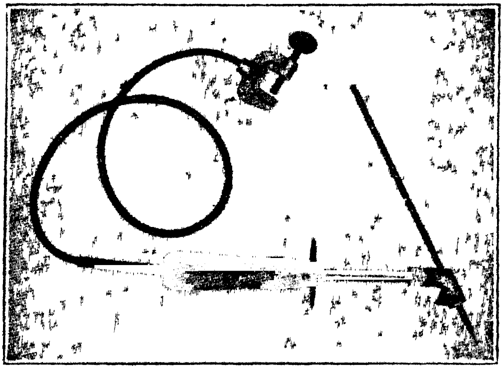


FIG 1,825—Electric Storage Battery Co, arc lead burning outfit *In assembling* a storage battery element, a negative plate is laid down with a separator on it, then a positive plate, separator, negative plate, etc The plates are so placed that all the lugs of the positive plates are on one side and all the lugs of the negative plates are on the other side A strip, consisting of flat strips of lead or lead alloy, having rectangular openings in it of the same dimensions as the cross section of the lug of the plates these openings being spaced to register with the lugs, is then placed over the plate lugs of the positive plates, and a similar strap is placed over the lugs of the negative plates The lugs are then burned into integral union with the straps

1. Air and artificial illuminating gas.
2. Air and hydrogen.
3. Oxygen and artificial illuminating gas;

4. Oxygen and natural illuminating gas.
5. Oxygen and acetylene.
6. Oxygen and hydrogen.

Both gases must be under some pressure, the amount depending on the combination used and the distance of the source of supply from the work.

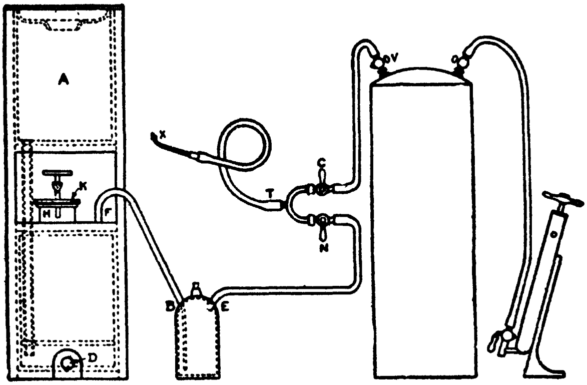


FIG. 1,826.—Hydrogen gas generator for lead burning. A complete lead burning outfit consists of the following parts: 1, hydrogen gas generator; 2, trap for cleaning the gas and for preventing the flame getting back in the generator; 3, air pump; 4, air tank; 5, blow pipe; 6 lead burner's mixing tee; 7, suitable length of 5/16 inch soft rubber tubing. When the generator is to be used for lead burning, connect up the different parts of the apparatus as shown. Fill the trap ¾ full with water and be sure to connect the gas generator to the nipple on the bottle marked B. The stop cocks N and C, must be closed. See that the rubber plug at D, is secured in place. Put the required amount of zinc in the opening at H. (No. 1 generator requires: 15 lbs. zinc, 9 gals.water, 3 gals. vitrol. No. 2 generator requires: 20 lbs. zinc, 15 gals. water, 5 gals. vitrol). After putting in the zinc, add the water and then the sulphuric acid, *and note that the water must be always be put in before the acid.*

NOTE.—***When making the connection*** for the hydrogen gas generator shown in fig. 1,826, be sure that there are no low points in the hose between E and N, as water is liable to accumulate at these low places, which will make the gas damp which is detrimental to the burning. If water get into the line, kink the hose between F and B, detach the hose at E, and blow out the water with air by opening the cocks, N, C and V. The length of the hose between T and X, must not be longer than five feet as the cocks N and C, must always be within the reach of the man who is using the flame. When ready to use the flame, open N, which allows the hydrogen gas to escape. Light the same with a match and adjust the air cock C, until the desired flame is obtained Different classes of work require different flames, which can be obtained by changing the tips and by varying the amount of gas and air with the cocks N and C. When the generaator is laid up for the night, or when the charge is exhausted, pull the hose off at F, and draw off the solution by removing the plug at D. The generator should then be thoroughly washed by pouring water in A.

Air, oxygen, acetylene and hydrogen may be supplied in separate tanks under pressure.

In all cases, a mixing Y or chamber of some sort must be used, together with a burning tip and sufficient hose to connect the various parts. Where oxygen is employed, the mixing should be done right at the burning

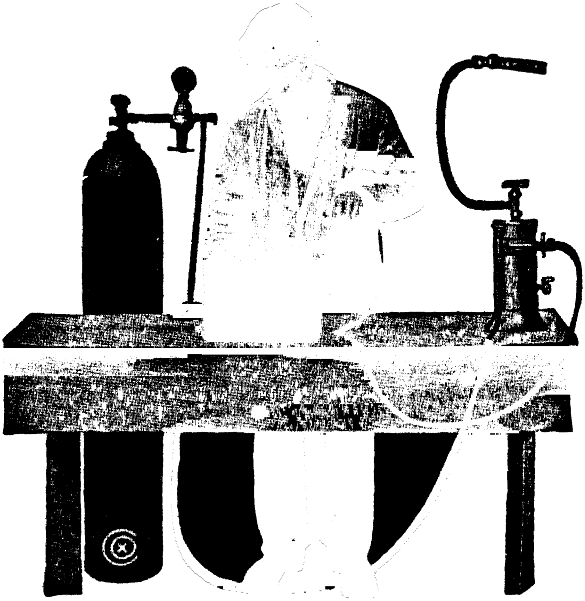
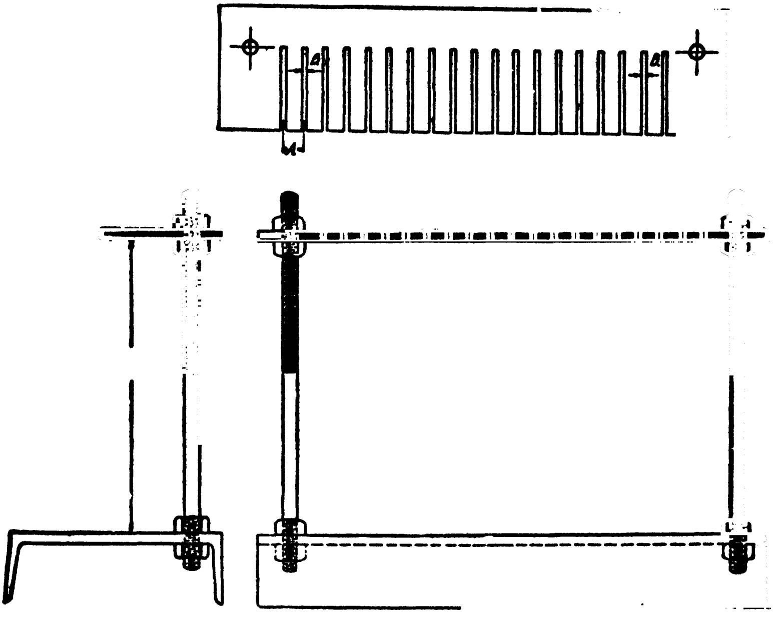


FIG. 1,827.—Oxygen illuminating gas lead burning outfit. Lead burning consists of fusing component parts of the battery together by the use of a hot flame or a white hot carbon pencil. The most widely used outfits using a flame are as follows: 1, illuminating gas and compressed air. This flame is synonymous with that given by the well known Bunsen burner. It is not a satisfactory flame for lead burning; 2, hydrogen gas and compressed air. Where hydrogen can be procured in tanks this is found to be a very satisfactory outfit, as it produces a hotter flame than that of the illuminating gas with compressed air, and where a great amount of work is to be done it saves considerable time; 3, oxygen gas and illuminating gas. This is the most satisfactory outfit, inasmuch as no compressed air is required, and commercial oxygen can be obtained practically throughout the United States. It is also much more economical than hydrogen and air. The oxygen can also be used for removing carbon from gas engine cylinders. The method of this carbon removal is to blow the gas on the carbon and touch it off with a match. The carbon and oxygen will form into an inflammable carbon oxide gas, thus removing the carbon from the cylinder; 4, oxygen gas and hydrogen gas. This combination is not as economical as oxygen and illuminating gas, and the flame produced is much hotter and not as suitable for lead burning.

tip, in which case the mixing chamber and burning tip are combined into one piece. The use of oxygen also requires a special valve.

The Electric Storage Battery Company has developed outfits for using the first two combinations. The illuminating gas outfit is designed for use with the ordinary city gas supply; *natural gas cannot be used.* Compressed air is necessary, the pressure ranging from 5 to 10 lbs.

The carbon burning outfit as shown in fig. 1,831 consists of the following



FIGS. 1,828 to 1,830.—Gould burning rack for burning plates into group. The rack is adjustable for height, and can be supplied with guides having proper spacing for all batteries manufactured.

parts: Carbon holder with cable, clamp and carbon rods. It is not meant to be used where considerable lead burning is done. The method of using it for reburning connectors is as follows:

One terminal of a spare 6 volt battery is connected by a piece of cable with the connector to be burned. The cable can be made fast to the latter by means of a clamp and care should be used that the surfaces are clean and a good contact secured. The cable attached to the carbon holder is then clamped to the spare battery at the other terminal. Touch the carbon to the joint and hold there; due to the flow of the current, it rapidly becomes red and then white hot. By moving it around, always keeping it in contact with the lead, the joint can be puddled.

To supply lead to fill the joint, a lead strip or extra connector can be used, simply introducing the end into the puddle of lead, touching the hot carbon. The carbon projecting past the holder should be slightly tapered or sharpened and should project past the holder about 1 in. After the joint is made, the top can be smoothed off by running the carbon over it a second time. The carbon (holder and all) should be occasionally dipped into a pail of water to keep it cool, as otherwise the holder and insulation may be damaged and it will become so hot as to make it uncomfortable to hold. Wetting the carbon does not affect the operation in any way, as it rapidly heats up again.

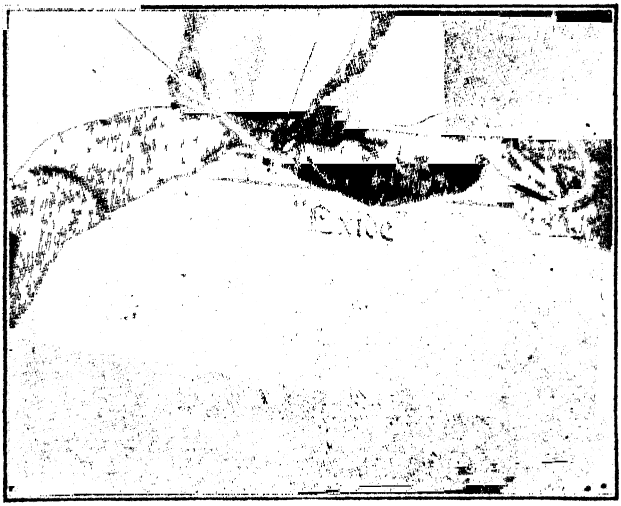


FIG. 1,831.—Method of lead burning with Exide carbon burning outfit.

After being used for a short time, it may be found that the carbon will not heat properly, due to a film of scale formed on the surface. This should be cleaned off with a knife or file, as occasion requires. Smoked or dark glasses should be used to protect the eyes from the intensity of the light.

In order to avoid the possibility of an explosion of the gaseous mixture contained in the upper part of a cell, when doing repair work with a gas flame or carbon burning outfit, the following precautions should be taken:

1. The filling plugs should be in place, and the entire battery, with the exception of the part on which the burning operation is to be performed, should be covered by a cloth wet with water.

2. The cloth should be pressed down upon the vents of the cells or wet waste may be packed around and over the vents.

3. A large piece of burlap or a towel thoroughly soaked in water is suitable. The wet cloth is recommended for two reasons: *a*, it prevents the burning flame or arc communicating to the interior of the cell, and *b*, if an explosion should occur, the cloth will prevent the solution and small parts being thrown about.

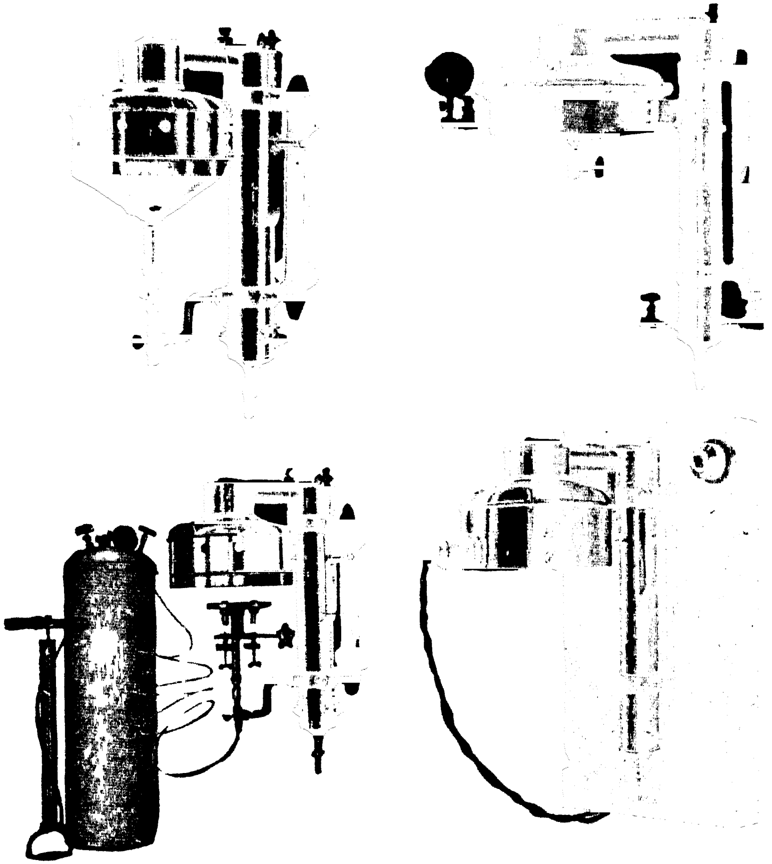
Disconnecting Cells.—The best method of disconnecting cells assembled with pillar straps, for the purpose of replacing broken jars, cleaning or taking out of commission, is to use a five-eighth inch twist drill, in a carpenter's brace, boring down into the top of the pillar about one-quarter inch; then pull off the connector sleeve from the pillar. By following this method, all parts may be used again.

Taking Batteries out of Commission.—Where a battery is

NOTE.—***The characteristic properties of concentrated sulphuric acid*** are very marked. Its freedom from odor, oily appearance, and its great weight, distinguish it from other liquids. The pure concentrated commercial acid has a density which usually reaches 1.842, and its boiling point is about 640° F. The absolutely pure acid is perfectly colorless, but usually, even that used in laboratories, has a peculiar grayish color, due to slight traces of organic matter. Sulphuric acid is exceedingly hydroscopic, and when exposed to the air it rapidly increases in bulk, owing to absorption of atmospheric moisture.

NOTE.—***Clamps*** not made of metal similar to that of the connecting strips, frequently give trouble from the galvanic action due to the contact of dissimilar metals in the presence of moisture which causes the destruction of either the connecting strip or the clamp. Such troubles can be avoided by placing a thin strip of sheet zinc between the lead strip and the clamp. Under these circumstances the zinc will crumble away, and can be replaced without much inconvenience and very little expense, while the clamps and connecting strips will remain uninjured.

to be out of service for several months, and it is not convenient to give it the freshening charge every two weeks, it should be taken out of commission.



Figs. 1,832 to 1,835.—Rochlitz automatic water still. A still removes iron, chlorine, nitrates and other impurities from raw water. Iron causes self discharge of batteries; chlorine and nitrate causes disintegration of the positive plates. The various arrangements shown are: 1, for artificial or natural gas; 2, for attaching to boiler; 3, for oil burner; 4, for electric heater.

COMPARISON OF THE BAUMÉ AND SPECIFIC GRAVITY SCALES AT 60° FAHRENHEIT

Degrees Baume	*Specific Gravity*	*Degrees Baume*	*Specific Gravity*	*Degrees Baume*	*Specific Gravity*	*Degrees Baume*	*Specific Gravity*
0	1.000	17	1.133	34	1.306	51	1.542
1	1.007	18	1 142	35	1.318	52	1.559
2	1.014	19	1.151	36	1.330	53	1.576
3	1.021	20	1.160	37	1.342	54	1.593
4	1.028	21	1.169	38	1.355	55	1.611
5	1.036	22	1.179	39	1.366	56	1.629
6	1.043	23	1.188	40	1.381	57	1.648
7	1.051	24	1.198	41	1.394	58	1.666
8	1.058	25	1.208	42	1.408	59	1.686
9	1.066	26	1.218	43	1.421	60	1.707
10	1.074	27	1.229	44	1.436	61	1.726
11	1.082	28	1.239	45	1.450	62	1.747
12	1.090	29	1.250	46	1.465	63	1.768
13	1.098	30	1.261	47	1.479	64	1.790
14	1.107	31	1.272	48	1.495	65	1.812
15	1.115	32	1.283	49	1.510	66	1.835
16	1.124	33	1.295	50	1.526		

Strength of Dilute Sulphuric Acid of Different Densities at 59° Fahr.

Per cent. of Sulphuric Acid	Specific Gravity	Per cent. of Sulphuric Acid	Specific Gravity
100	1.842	23	1.167
40	1.306	22	1.159
31	1.231	21	1.151
30	1.223	20	1.144
29	1.215	19	1.136
28	1.206	18	1.129
27	1.198	17	1.121
26	1.190	16	1.116
25	1.172	15	1.106
24	1.174	14	1.098

Ques. Describe the method of taking a battery out of commission.

Ans. The battery is charged in the usual manner, until the specific gravity of the electrolyte of every cell has stopped rising over a period of one hour (if there be any low cells, due to short circuits or other cause, they should be put in condition before the charge is started, so that they will receive the full benefit of it).

The cells may now be disconnected and covers and elements removed from the jars (if sealed, the compound is loosened with a hot putty knife). The elements are placed on their sides with the plates slightly spread apart at the bottom, the separators withdrawn, and the positive and negative groups pulled apart. The electrolyte is washed off with a gentle stream of water and the plates allowed to drain and dry. The positive plates are ready to be put away. When dry, the negatives are completely immersed in electrolyte (of about 1.275 specific gravity), and allowed to soak for three or four hours. The jars may be used for this purpose. After rinsing and drying, they are ready to be put away; wash also the rubber separators.

Wood separators, after having been in service, will not stand much handling and had better be thrown away. If it be thought worth while to keep them, they must be immersed in water or weak electrolyte, and in re-assembling, the electrolyte must be put into the cells immediately, as wet wood separators must not stand exposed to the air.

Ques. What precaution should be taken with the jars?

Ans. They should be thoroughly cleaned with fresh water, no sediment being allowed to remain.

Putting Batteries into Commission.—When re-assembling a battery, it should be treated in the same manner as if it were new and the regular instructions for assembling and putting a new battery into commission followed.

Cleaning Jars.—The jars should be thoroughly cleaned with fresh water, no sediment being allowed to remain.

1. Double Cover Batteries

The type battery considered in this chapter to illustrate battery repair methods is a ***Gould*** 6 volt 81 ampere hour size of the double cover sealed type.

Before starting to dismantle a battery a sketch should be made showing the inter-cell connections and position of terminals for guidance in reassembling.

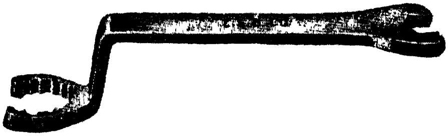


FIG. 1836,.—"Exide" connector puller for removing connectors.

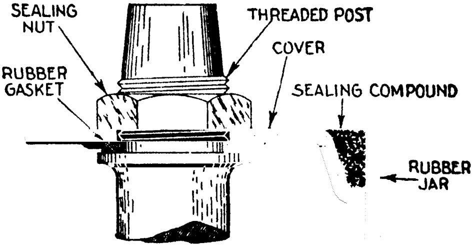


FIG. 1,837.—***Battery repairs 47.*** The battery post of single cover battery is threaded and provided with a flange on which the cover rests, with a soft rubber sealing gasket between. A lead or hard rubber nut secures the cover to the post. To remove cover simply unscrew the nuts on positive and negative post. In replacing a cover of this type the nut should be prevented backing off by breaking the thread in the post, just above the nut, by means of a prick punch.

2. Single Cover Batteries

Batteries are now constructed with single moulded covers with a depression around the edge into which the sealing compound is poured.

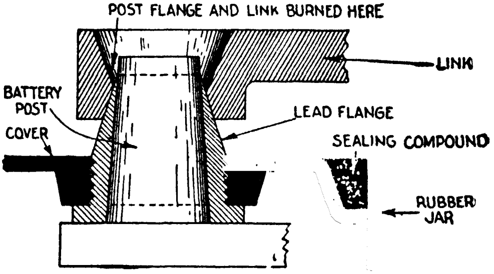


FIG. 1,838.—***Battery repairs 48.*** Sealing around posts of single cover battery is made by means of sealing compound. There are several designs of this kind but it is in any case necessary to remove the compound or to soften it by heating before cover can be removed.

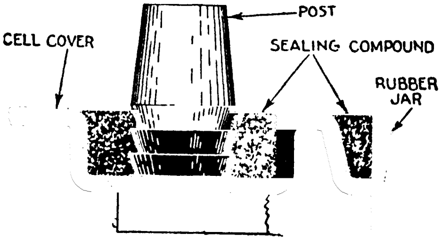


FIG. 1,839.—***Battery repairs 49.*** A lead flange is screwed into the cover from the lower side. The inside of this flange fits the battery post and the outside tapers above the top of the cover so that when the cell connector is placed in position the three parts, namely—post, flange and connecting link—are burned together at the top. When the connecting links are removed from both posts by drilling, the cover is free and can be lifted off. In replacing the cover on such a battery great care must be taken that the edge of the lead flange is burned into the joint; a new flange being used if necessary. Aside from the points described above repairs to a single cover battery are to be handled as before described.

NOTE.—When cells are equipped with top straps, the straps should be cut with a sharp knife or chisel midway between the cells.

NOTE.—***Pole testing paper.*** Make a thin solution of white starch and soak strips of thin white blotting paper in it, and set aside in a clean, dry place to dry. Dissolve ½ oz. of potassium iodide in one pint of water. Immerse the strips in the solution for a few seconds and again dry. This paper, when moistened and used in the usual way, turns violet at the positive pole.

NOTE.—***If the active material*** in the negative plates extend beyond the ribs of the grid (the supporting frame), it should be at once pressed back into place, care being taken to prevent the plates drying before this is done. The most suitable and convenient method for pressing is to place between the plates smooth boards of a thickness equal to the distance between the plates and then put the groups under pressure

In order to remove the elements from such cells it is only necessary to remove the connecting links as previously described and remove the compound from the channel around the jar formed by the depression of the cover. The element can then be removed with the cover attached to the posts.

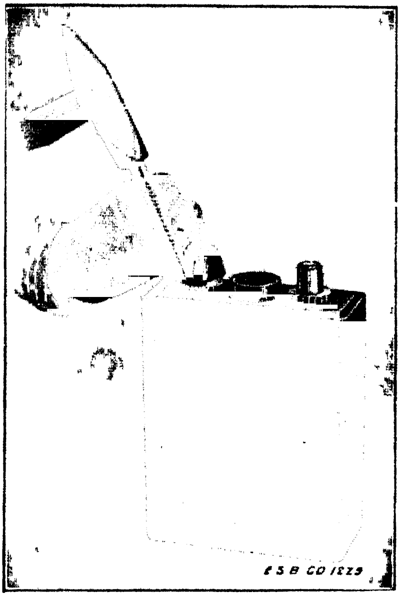
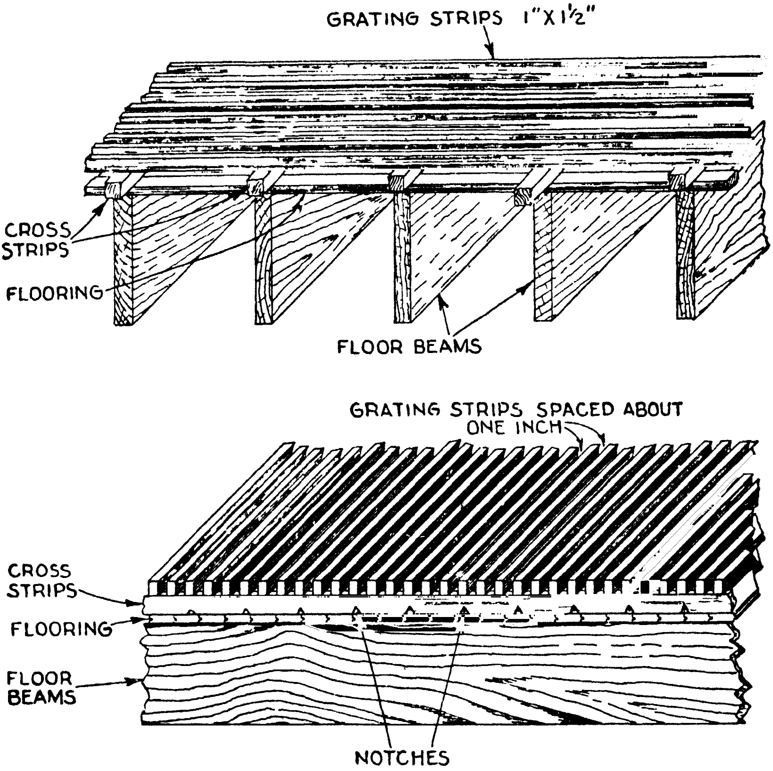


FIG. 1,840.—Method of locking seal nut on Exide single cover battery.

The method of removal of the cover from the element will depend upon the means by which it is attached and sealed to the posts.

The most usual methods are shown in the accompanying cuts.

NOTE.—*A very effective way* of softening the compound for unsealing any type is to place the cell or battery in a steam box. This consists simply of a box or oven into which live steam is injected at low pressure. By so doing, the rubber parts are made somewhat pliable and are much less likely to be cracked in handling, especially in cold weather. Another method is to stand the cell in very hot water, taking care that the water does not get inside of the cell.



FIGS. 1,841 and 1,842.—Wooden grating on floor of shop to give dry walking surface for repairmen.

Table of Voltage Change as Affected by Discharge Rate*

8	hour rate	.05 volt
6	" "	.065 "
4	" "	.09 "
3	" "	.11 "
2	" "	.14 "
1½	" "	.18 "
1	" "	.21 "

TEST QUESTIONS

1. *Give a list of tools, equipment and spare parts necessary for battery repair.*
2. *What should be done on receipt of a battery?*
3. *How should a new battery be prepared for service?*
4. *Describe the Edison battery.*
5. *What should be done if a wood insulated battery has been shipped uncharged; what if rubber insulated?*
6. *Describe method of preparing electrolyte.*
7. *What precaution should be taken when mixing water with sulphuric acid?*
8. *What kind of water should be used?*
9. *Why should pure sulphuric acid not be added to a cell?*
10. *What may be said with respect to impurities in the electrolyte?*
11. *Describe several tests for impurities.*
12. *What should be the specific gravity of electrolyte in tropical countries?*
13. *Describe how a battery should be installed.*
14. *How is a new battery installed in a car?*
15. *Name two ways of storing a battery.*
16. *When should a battery be put in wet storage and when in dry storage?*
17. *How is a battery tested in the car?*
18. *If the gravity of electrolyte be not the same in all cells, what should be done?*
19. *How are faults located in a battery?*
20. *How is the necessity for opening cells determined?*

21. *What is the proper method of adjusting the gravity?*
22. *Describe the process of lead burning.*
23. *How is a hydrogen gas generator constructed?*
24. *How should batteries be taken out of commission?*
25. *What precaution should be taken with the jars?*
26. *How are covers removed from single cell batteries?*
27. *Describe at very great length how a battery is repaired.*

CHAPTER 46

Radio Batteries

Early in the eighteenth century, an Italian scientist Alessandro Volta, discovered that if two dissimilar substances, such as zinc and carbon were placed in an acid solution, the chemical action would accumulate electrons on the zinc rod making it negative with respect to the carbon, which does not react with the acid.

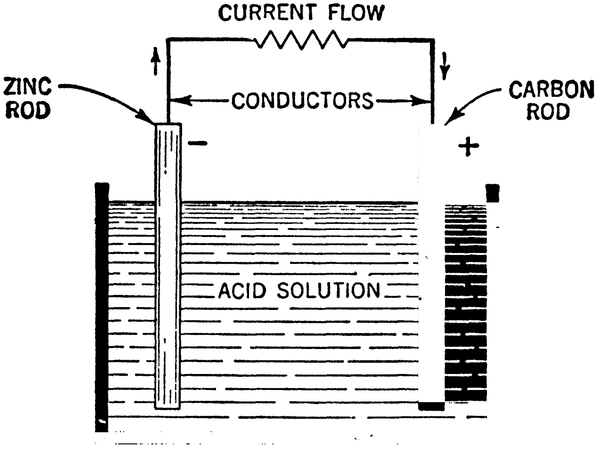


FIG. 1—Illustrating construction principles of the Voltaic cell.

Volta also noted that if a wire joined the ends of the zinc and carbon electrodes, outside of the liquid, a current flowed continuously in the circuit from the zinc to the carbon. Such a device is called a Voltaic Cell in honor of its inventor.

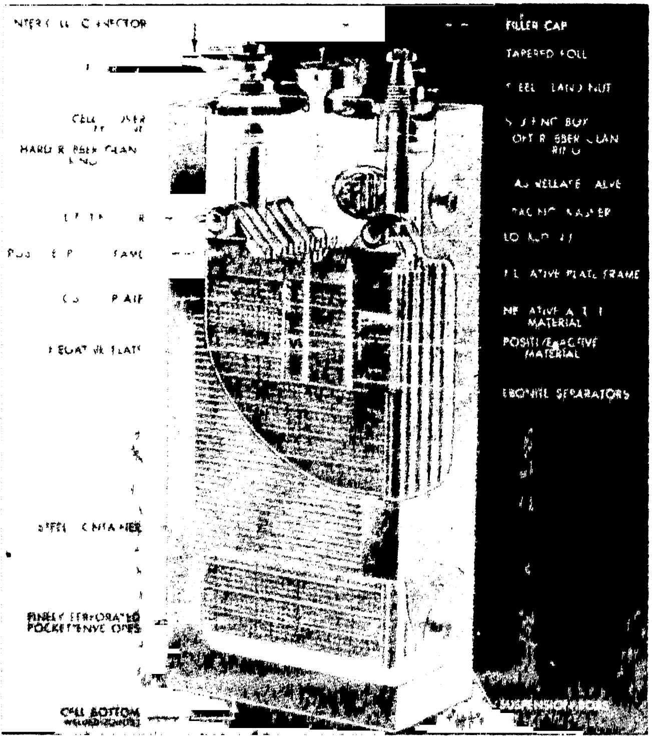


FIG. 2—Showing construction principles of a nickel cadmium storage battery. In a battery of this type nickel and cadmium function as the active materials while potassium hydroxide in solution serves as the electrolyte. (Courtesy NIFE Incorporated.)

While seeking still further to increase the capacity of his discovery, Volta found that by joining a large number of such cells in series or parallel in the form of a battery, a considerable amount of power could be obtained.

In dealing with batteries, certain distinctions should be made with respect to the terms used:

A primary cell consists of a vessel containing a liquid in which two dissimilar metal plates are immersed.

A battery consists of two or more cells joined together (in series or parallel) so as to form a single unit.

The fluid or acid solution used in a cell is termed the *electrolyte* or *exciting* fluid.

A dry cell is one in which the electrolyte has been substituted for a paste of certain chemicals in combination with ammonium chloride.

A storage battery consists of a connected group of electrochemical cells for the generation of electrical energy in which the cells after being discharged may be restored to a charged condition by passing a current through them in a direction opposite to the flow of current during the discharge period.

The Dry Cell.—The dry cell or battery is used in radio receivers of the portable type to supply "A" and "B" power. In England the filament lighting battery is known as the low-tension battery usually abbreviated *L.T.*; whereas the plate battery is termed *H.T.*, for high-tension. In the United States the term "A" and "B" battery has found acceptance, the *A* battery being that used for energizing the filaments, and the *B* battery that used for energizing the plate circuit.

The dry cell is being used in applications where considerable jarring or motion is involved and its use in portable radios is only one of its numerous duties.

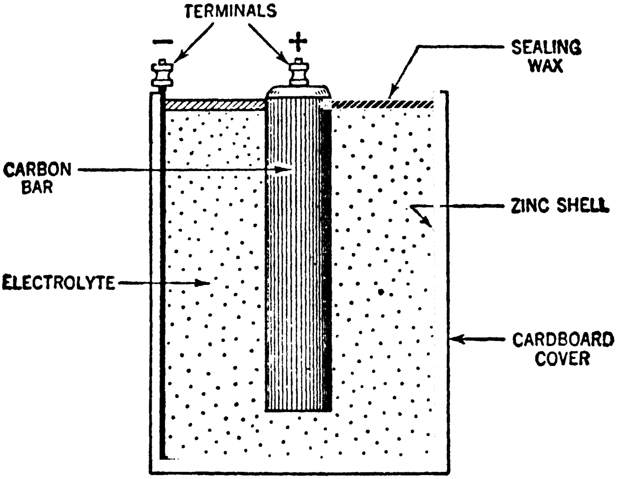


FIG. 3—Cross-section of typical dry cell showing construction. The electrolyte commonly used consists of a paste made up of ammonium chloride, manganese dioxide, sawdust and graphite.

How a Dry Cell Works.—There is nothing mysterious about a dry cell or the manner in which it works. In its usual form a dry cell consists of a zinc can into which are packed certain active chemical materials which combine with the zinc to produce an electrical pressure or voltage. The voltage thus produced is the result of the chemicals used and is always the same regardless of the size of the dry cell. A new dry cell has a pressure of about 1.5 volts, and this is true whether the dry cell be a very small one like a flashlight battery or a large 6 in. dry cell.

A dry cell is simply a package of electricity done up in convenient form. When you purchase a dry cell, the commodity actually bought is stored up electricity and the dry cell which gives you the most electricity for a given price is the cell you want to use.

The unit of quantity of electricity is commonly known as the ampere hour. It is the amount of electricity which will flow from a battery that is delivering one ampere for a period of one hour or one-half an ampere for a period of two hours, etc. If the number of ampere hours in a dry cell be known and also the rate at which this electricity was extracted from the cell, it would be a simple matter to find out how long the dry cell would last. To determine this, divide the ampere hour capacity of the dry cell by the current which it is delivering in amperes, and the result is the number of hours that the cell will last.

In practice it is almost impossible to apply this simple calculation to dry cells because it is very difficult to predict just how many ampere hours a dry cell will deliver.

The amount of electricity which is actually in a dry cell and the amount which can be obtained from it are two different things, and sometimes the difference is surprisingly large.

Battery Connections.—There are three methods of connecting cells to form a battery. They may be connected:

1. In series
2. In parallel
3. In series-parallel.

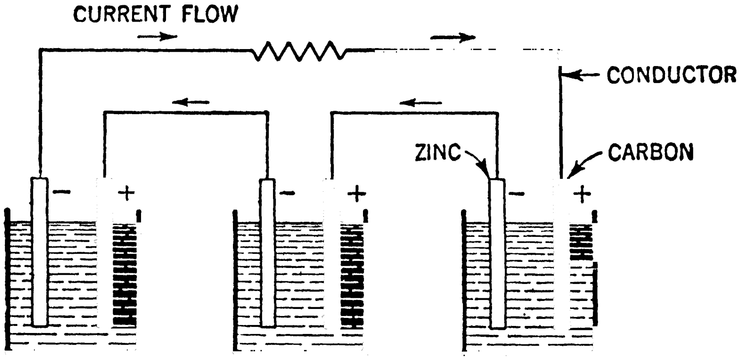


FIG. 4—Showing three series connected Voltaic cells. To obtain a series connected circuit the plus pole of one cell must be joined with the negative pole of the next cell as illustrated.

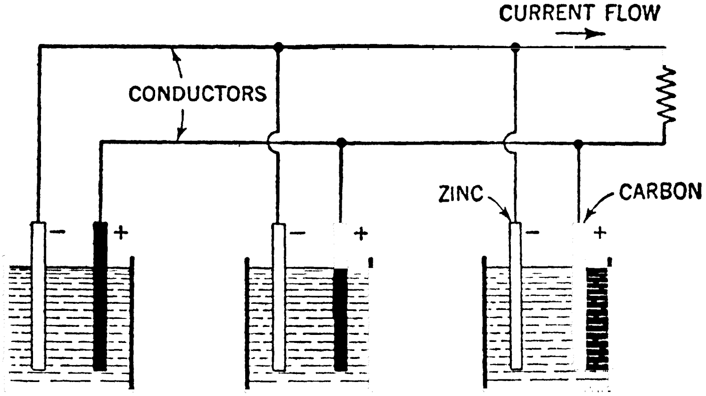


FIG. 5—Three Voltaic cells connected in parallel. To obtain a parallel connected circuit, the plus poles are joined together to form one part of the circuit and the negative poles are joined together to form the other.

A series connection consists in joining the positive pole of one cell to the negative pole of the other to form a circuit. A series connection adds the voltage of each cell; that is, the voltage of the battery will equal the sum of the voltage of each cell.

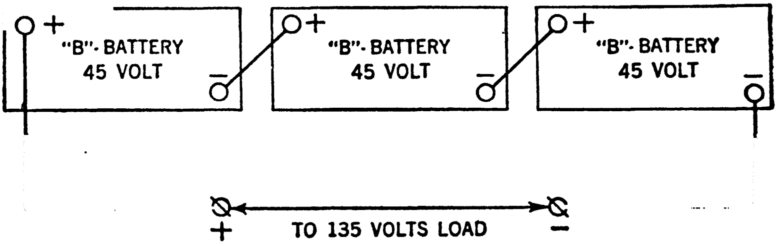


FIG. 6—Showing three series connected "B" batteries, each battery delivering a potential of 45 volts. A single battery or a series connected group of batteries such as illustrated are commonly used to supply the plate voltage on small portable type radio receivers.

A parallel or multiple connection consists in connecting the positive terminal of one cell with the positive terminal of another cell and the negative terminal of the first cell with the negative terminal of the second cell. A parallel connection adds the amperage of each cell, that is, the amperage of the battery will equal the sum of the amperage of each cell.

A series-parallel connection consists of two series sets of cells connected in parallel. The voltage of a series parallel connection is equal to the voltage of one cell multiplied by the number of cells in one battery, and the amperage is equal to the amperage of one cell multiplied by the number of batteries.

Thus, to obtain 6 volts from four dry cells, each of which has a potential of 1½ volts, a series connection will be necessary. If, on the other hand, only 1½ volts be required, but it is desired to obtain a current flow of four times that furnished by each cell, a parallel connection should be made.

CHAPTER 46A

Automotive Batteries

The 12-volt electrical system adopted on late model cars is used for two main reasons:

1. To provide adequate electrical power to supply the increasing number of electrical accessories used.
2. To make available higher voltages to the ignition system for new high speed, high compression engines.

The advantage of doubling the voltage may readily be comprehended if it be realized that in any direct current electrical system the power obtained is direct proportional to the product of current and voltage. Thus, for example, with a 12-volt system, the same amount of electrical power can be delivered with half the amperage, because power is measured in watts, which are simply amperes multiplied by volts. When a generator is required to deliver, say 600 watts, this amount of power can be delivered in two ways, namely 100 amperes at 6 volts or 50 amperes at 12 volts, since in each case the power obtained will be the same or 600 watts.

Because of the fact that it is the current flow in amperes that determines the conductor size, it follows that smaller and more economical wires can be used to deliver the same amount of power in a twelve-volt system as the much larger sizes would deliver in a six-volt system.

In this connection it should be noted that with the introduction of the 12-volt electrical system numerous changes had to be made in the electrical units. Thus, for example, the battery, starter, generator, the various electrical motors, light bulbs, etc., all had to be redesigned to comply with this higher voltage. The electrical circuits, that is, connections to the individual electrical units, will, however, be similar in both voltage systems.

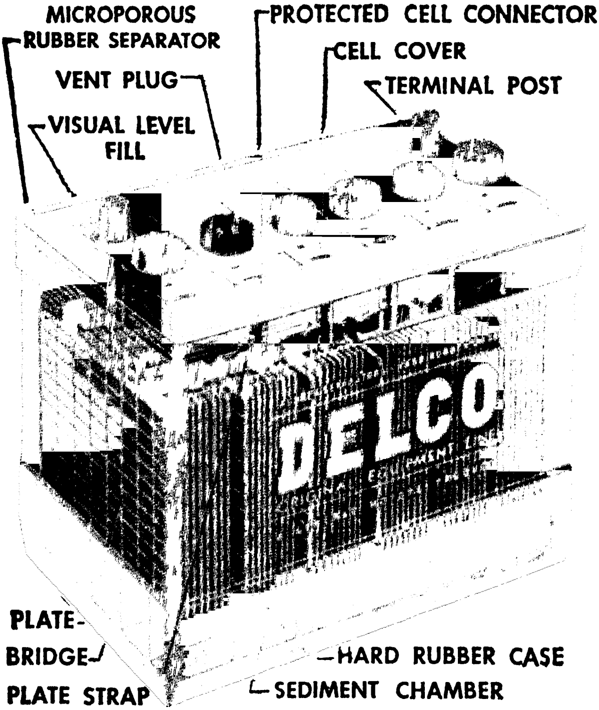


FIG. 1.—Illustrating construction details of typical lead-acid battery.

In automobile installations, several cells are used in groups, or a battery. The number of cells and their size, depends upon the service required. The usual, or common assembly method is to connect these cells in series, that is, the positive of one cell is connected to the negative of the next cell, and so on, to the end of the row.

Battery Capacity Rating.—The amount of electricity which a battery will deliver within a certain time limit is known as its capacity or *ampere-hour capacity.* The 20-hour rate has been prescribed by the S.A.S. (Society of Automotive Engineers) as an accepted standard for automobile batteries. To measure the capacity, a battery is discharged continuously at the specific rate until the voltage drops too low for efficient use. Thus, for example, a battery that will deliver 3.5 amperes for 20 hours is said to have a capacity of 70 ampere-hours.

This measurement is of particular interest because it indicates what may be expected of a battery in the way of satisfactory performance. The capacity of a battery depends upon the amount of active material that can react with the electrolyte. Obviously this depends upon the thickness and design of the plates, hence, the number of plates is not always an accurate index of the capacity.

Also, one of the characteristics of a storage battery is that its total ampere-hour capacity is dependent upon the rate of discharge. The lower the rate of discharge, the greater the ampere-hour capacity will be; whereas, the higher the discharge rate, the lower will be the capacity. Thus, a battery having a 70 ampere-hour capacity at a 3.5 ampere discharge rate will ordinarily have a capacity of over 70 ampere-hour at a lower discharge rate.

Preparing Dry Charged Batteries for Service.—To prepare "dry charge" batteries for service use approved battery-grade acid electrolyte (1.265 sp. gr. at 80° F.). Care should be exercised in its use to prevent bodily injury or damage to clothing or other material resulting from actual contact with the electrolyte. Electrolyte should be added to dry charged batteries in an area where water is readily available for flushing in case the electrolyte comes in contact with the body.

It is strongly recommended that a person filling batteries with electrolyte wear glasses (preferably safety glasses) to prevent possible damage to the eyes should any spattering of the electrolyte occur. Proceed as follows:

1. Remove dry charged battery from its original carton.
2. Remove the vent plugs and discard the white restrictors found in the vent openings.
3. Using a glass or acid-proof plastic funnel, fill each battery cell with electrolyte. *Do not use a metal funnel for filling the battery.* The cell is properly filled when the electrolyte level rises to the split ring at the bottom of the vent well. Do not overfill. In most cases some electrolyte will remain in the electrolyte container after the battery has been completely filled.
4. After filling cells, wait five to ten minutes and add additional electrolyte, if necessary, to bring the electrolyte to the proper level.

Battery Function.—The battery has three major functions: (1) It provides a source of energy for cranking the engine. (2) It acts as a stabilizer to the voltage in the electrical system.

(3) It can for a limited time furnish energy when the demands of the electrical units in operation exceed the output of the generator.

In order for the battery to continue to function, it is necessary that current withdrawn from the battery be balanced by current input from the generator so that the battery is maintained in a properly charged condition. If the outgo exceeds the input the battery will become discharged so that it cannot supply sufficient energy.

The state of charge of the battery as well as the temperature of the electrolyte has an important bearing on its capacity for supplying energy. Battery efficiency is greatly reduced by decreased electrolyte temperature as it has a decided numbing effect on its electrochemical action. Under high discharge such as cranking, battery voltage drops to lower values in cold temperatures than in warm temperatures.

In extremely cold climates it is important to keep batteries in a nearly full charged condition to avoid the possibility of freezing, which will damage any battery.

Battery Testing.—There are several different ways of testing storage batteries to determine their state of charge or to locate irregularities and identify batteries in worn-out condition.

Specific Gravity Test.—It is advisable to occasionally check the condition of the battery electrolyte with a hydrometer in order to determine whether the generating system is maintaining the battery in a proper state of charge. This is particularly important during cold weather.

The hydrometer measures the percentage of sulphuric acid in the battery electrolyte in terms of specific gravity. As a battery drops from a charged to a discharged condition the acid leaves the solution and enters the plates, causing a decrease in specific gravity of the electrolyte. By measuring specific gravity of the electrolyte with a hydrometer, an indication of the approximate state of charge of the battery is obtained.

The specific gravity of the electrolyte varies not only with the percentage of acid in the liquid, but also with the change in temperature. As temperature increases, the electrolyte expands so that the specific gravity is reduced. As temperature drops, the electrolyte contracts so that the specific gravity increases. Unless these variations in specific gravity are taken into account, the specific gravity obtained by the hydrometer may not give a true indication of the state of charge of the battery.

Correction can be made for temperature by adding .004, usually referred to as 4 "points of gravity," to the hydrometer reading for every 10° F. that the electrolyte is above 80° F. or subtracting .004 for every 10° F. that the electrolyte is below 80° F.

If the electrolyte temperature be not too far from the 80° F. standard, or if only an approximate idea of the specific gravity reading be required, it will not be necessary to make the temperature correction. In this connection, it should be noted, that there are hydrometers available which have built in thermometer and temperature scale correction, which hydrometer, if used, will simplify the operation of obtaining a true specific gravity reading.

Tables and Data

Formulae for Calculating Electrical Properties of Circuits

Desired Data	ALTERNATING CURRENT			Direct Current
	Single Phase	Two Phase* Four Wire	Three Phase	
KILOWATTS	$\frac{I\,E\cos\theta}{1000}$	$\frac{2\,I\,E\cos\theta}{1000}$	$\frac{1.73\,I\,E\cos\theta}{1000}$	$\frac{I\,E}{1000}$
KILOVOLT-AMPERES	$\frac{I\,E}{1000}$	$\frac{2\,I\,E}{1000}$	$\frac{1.73\,I\,E}{1000}$	$\frac{I\,E}{1000}$
HORSEPOWER OUTPUT,	$\frac{I\,E\cos\theta \times \text{Eff.}}{746}$	$\frac{2\,I\,E\cos\theta \times \text{Eff.}}{746}$	$\frac{1.73\,I\,E\cos\theta \times \text{Eff.}}{746}$	$\frac{I\,E \times \text{Eff.}}{746}$
AMPERES WHEN HORSEPOWER IS KNOWN	$\frac{HP \times 746}{E\cos\theta \times \text{Eff.}}$	$\frac{HP \times 746}{2\,E\cos\theta \times \text{Eff.}}$	$\frac{HP \times 746}{1.73\,E\cos\theta \times \text{Eff.}}$	$\frac{HP \times 746}{E \times \text{Eff.}}$
AMPERES WHEN KILOWATTS ARE KNOWN	$\frac{KW \times 1000}{E\cos\theta}$	$\frac{KW \times 1000}{2\,E\cos\theta}$	$\frac{KW \times 1000}{1.73\,E\cos\theta}$	$\frac{KW \times 1000}{E}$
AMPERES WHEN KILOVOLT-AMPERES ARE KNOWN	$\frac{KVA \times 1000}{E}$	$\frac{KVA \times 1000}{2\,E}$	$\frac{KVA \times 1000}{1.73\,E}$	$\frac{KVA \times 1000}{E}$
e_r WHEN e_s, I, cos θ ARE KNOWN	$\sqrt{e_s^2 - I^2(X\cos\theta \mp R\sin\theta)^2} - I\,(R\cos\theta \pm X\sin\theta)$			....

*In three wire two phase circuits, the current in the common conductor is 1.41 times that in either phase conductor.

NOTATION

$\cos\theta$ = Power factor of load
E = Volts between conductors
e = Volts to neutral
Eff. = Efficiency of motor
e_r = Volts at receiving end

e_s = Volts at sending end
I = Line current amperes
R = Resistance in ohms to neutral
$\sin^2\theta = 1 - \cos^2\theta$
X = Reactance in ohms to neutral

Where double signs, such as ∓ or ± are shown, use upper one for lagging and lower one for leading power factor.

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gauge (B. & S.) English Units

Gauge No.	Diameter in mils at 20°C	Cross section at 20°C		Ohms per 1000 feet			
		Circular mils	Sq. inches	0°C (32°F)	20°C (68°F)	50°C (122°F)	75°C (167°F)
0000	460.0	211600	0.1662	0.04516	0.04901	0.05479	0.05961
000	409.6	167800	.1318	.05695	.06180	.06909	.07516
00	364.8	133100	.1045	07181	.07793	.08712	.09478
0	324.9	105500	.08289	.09055	09827	.1099	.1195
1	289.3	83690	.06573	.1142	.1239	.1385	.1507
2	257 6	66370	.05213	.1440	.1563	.1747	.1900
3	229.4	52640	04134	.1816	1970	.2203	.2396
4	204.3	41740	.03278	.2289	.2485	.2778	.3022
5	181.9	33100	.02600	.2887	.3133	.3502	.3810
6	162.0	26250	.02062	.3640	.3951	.4416	.4805
7	144.3	20820	01635	.4590	.4982	.5569	.6059
8	128 5	16510	01297	.5788	.6282	.7023	.7640
9	114.4	13090	01028	.7299	.7921	.8855	.9633
10	101.9	10380	.008155	.9203	9989	1.117	1.215
11	90.74	8234	.006467	1.161	1.260	1.408	1.532
12	80.81	6530	005129	1 463	1.588	1.775	1.931
13	71.96	5178	.004067	1.845	2.003	2.239	2.436
14	64.06	4107	.003225	2.327	2.525.	2 823	3.071
15	57.07	3257	002558	2.934	3 184	3.560	3.873
16	50.82	2583	002028	3.700	4 016	4.489	4.884
17	45.26	2048	001609	4.666	5.064	5.660	6.158
18	40.30	1624	.001276	5.883	6 385	7.138	7.765
19	35.89	1288	.001012	7.418	8.051	9.001	9.792
20	31.96	1022	.0008023	9.355	10.15	11 35	12.35
21	28.45	810.1	.0006363	11.80	12 80	14.31	15.57
22	25 35	642.4	.0005046	14 87	16.14	18.05	19.63
23	22 57	509 5	.0004002	18.76	20.36	22.76	24.76
24	20.10	404.0	.0003173	23.65	25.67	28.70	31.22
25	17 90	320.4	.0002517	29.82	32.37	36.18	39.36
26	15 94	254.1	0001996	37.61	40.81	45.63	49.64
27	14.20	201.5	.0001583	47.42	51.47	57.53	62.59
28	12 64	159.8	.0001255	59.80	64 90	72.55	78.93
29	11.26	126.7	.00009953	75.40	81.83	91.48	99.52
30	10.03	100.5	.00007894	95.08	103.2	115 4	125.5
31	8 928	79.70	00006260	119.9	130.1	145 5	158.2
32	7 950	63.21	00004964	151.2	164 1	183 4	199.5
33	7.080	50.13	00003937	190.6	206 9	231.3	251.6
34	6.305	39.75	.00003122	240.4	260.9	291.7	317.3
35	5.615	31.52	.00002476	303.1	329.0	367.8	400.1
36	5.000	25 00	.00001964	382.2	414.8	463.7	504.5
37	4.453	19.83	.00001557	482.0	523.1	584.8	636.2
38	3.965	15.72	.00001235	607.8	659.6	737.4	802.2
39	3.531	12.47	.000009793	766.4	831.8	929.8	1012
40	3.145	9.888	.000007766	966.5	1049	1173	1276

ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Single Conductor in Free Air

(Based on Room Temperature of 30 C. 86 F.)

Size AWG MCM	Rubber Type R Type RW Type RU (14–6) Thermoplastic Type T Type TW	Rubber Type RH	Thermoplastic Asbestos Type TA Var-Cam Type V Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impregnated Asbestos Type AI (14–8) Type AIA	Asbestos Type A (14–8) Type AA	Slow-Burning Type SB Weather-proof Type WP Type SBW
14	20	20	30	40	40	45	30
12	25	25	40	50	50	55	40
10	40	40	55	65	70	75	55
8	55	65	70	85	90	100	70
6	80	95	100	120	125	135	100
4	105	125	135	160	170	180	130
3	120	145	155	180	195	210	150
2	140	170	180	210	225	240	175
1	165	195	210	245	265	280	205
0	195	230	245	285	305	325	235
00	225	265	285	330	355	370	275
000	260	310	330	385	410	430	320
0000	300	360	385	445	475	510	370
250	340	405	425	495	530	....	410
300	375	445	480	555	590	....	460
350	420	505	530	610	655	....	510
400	455	545	575	665	710	....	555
500	515	620	660	765	815	....	630
600	575	690	740	855	910	....	710
700	630	755	815	940	1005	....	780
750	655	785	845	980	1045	....	810
800	680	815	880	1020	1085	....	845
900	730	870	940	....	....	....	905
1000	780	935	1000	1165	1240	....	965
1250	890	1065	1130	....	....	....	....
1500	980	1175	1260	1450	....	....	1215
1750	1070	1280	1370	....	....	....	....
2000	1155	1385	1470	1715	....	....	1405

CORRECTION FACTOR FOR ROOM TEMPERATURES OVER 30 C. 86 F.

C. F.							
40 104	.82	.88	.90	.94	.95	....	....
45 113	.71	.82	.85	.90	.92	....	....
50 122	.58	.75	.80	.87	.89	....	....
55 131	.41	.67	.74	.83	.86	....	....
60 140	....	.58	.67	.79	.83	.91	....
70 158	....	.35	.52	.71	.76	.87	....
75 167	....	....	.43	.66	.72	.86	....
80 176	....	....	.30	.61	69	.84	....
90 194	....	....	....	.50	.61	.80	....
100 212	....	....	....	....	.51	.77	....
120 248	....	....	....	....	....	.69	....
140 284	....	....	....	....	....	.59	....

ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Not More Than Three Conductors in Raceway or Cable

(Based on Room Temperature of 30 C. 86 F.)

Size AWG MCM	Rubber Type R Type RW Type RU (14–6) Thermo-plastic Type T (14–4/0) Type TW (14–4/0)	Rubber Type RH	Paper Thermo-plastic Asbestos Type TA Var-Cam Type V Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impreg-nated Asbestos Type AI (14–8) Type AIA	Asbestos Type A (14–8) Type AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340
250	215	255	270	315	335	.
300	240	285	300	345	380	.
350	260	310	325	390	420	
400	280	335	360	420	450	.
500	320	380	405	470	500	
600	355	420	455	525	545	.
700	385	460	490	560	600	
750	400	475	500	580	620	.
800	410	490	515	600	640	
900	435	520	555		..	
1,000	455	545	585	680	730	
1,250	495	590	645		...	.
1,500	520	625	700	785	.	...
1 750	545	650	735		...	...
2 000	560	665	775	840	...	.

CORRECTION FACTOR FOR ROOM TEMPERATURES OVER 30 C. 86 F.

C. F.						
40 104	82	88	90	94	95	...
45 113	71	82	85	90	92	.
50 122	58	75	80	87	89	. .
55 131	41	67	74	83	86	
60 140		58	67	79	83	91
70 158		35	52	71	76	87
75 167			.43	66	72	86
80 176			30	61	69	84
90 194				50	61	.80
100 212					51	.77
120 248			.		..	.69
140 284						59

FULL-LOAD CURRENT*
Direct-Current Motors

HP	115V	230V	550V
½	4.6	2.3	....
¾	6.6	3.3	1.4
1	8.6	4.3	1.8
1½	12.6	6.3	2.6
2	16.4	8.2	3.4
3	24.	12.	5.0
5	40	20	8.3
7½	58	29	12.0
10	76	38	16.0
15	112	56	23.0
20	148	74	31.
25	184	92	38.
30	220	110	46.
40	292	146	61
50	360	180	75
60	430	215	90
75	536	268	111
100		355	148
125		443	148
150		534	220
200		712	295

*These values for full-load current are average for all speeds.

FULL-LOAD CURRENT*
Single-Phase A.C. Motors

HP	115V	230V	440V
1/6	3.2	1.6	
¼	4.6	2.3	
½	7.4	3.7	
¾	10.2	5.1	
1	13.	6.5	
1½	18.4	9.2	
2	24.	12.	
3	34.	17.	
5	56.	28.	
7½	80.	40.	21.
10	100.	50.	26.

For full-load currents of 208 and 200-volt motors, increase corresponding 230-volt motor full-load current by 10 and 15 per cent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

Full-Load Current*

Two-Phase A.C. Motors (4-wire)

	Induction Type Squirrel-Cage and Wound Rotor Amperes					Synchronous Type †Unity Power Factor Amperes			
HP	110V	220V	440V	550V	2300V	220V	440V	550V	2300V
½	4	2	1	.8					
¾	4.8	2.4	1.2	1.0					
1	6.4	3.2	1.6	1.3					
1½	8.8	4.4	2.2	1.8					
2	11.2	5.6	2.8	2.2					
3		8	4	3.2					
5		13	7	6					
7½		19	9	8					
10		24	12	10					
15		34	17	14					
20		45	23	18					
25		55	28	22	6	47	24	19	4.7
30		67	34	27	7.5	56	29	23	5.7
40		88	44	35	9	75	37	31	7
50		108	54	43	11	94	47	38	9
60		129	65	52	13	111	56	44	11
75		158	79	63	16	140	70	57	13
100		212	106	85	21	182	93	74	17
125		268	134	108	26	228	114	93	22
150		311	155	124	31		137	110	20
200		415	208	166	41		182	145	35

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*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the name-plate current rating should be used.. Current in common conductor of 2-phase, 3-wire system will be 1.41 times value given.

†For 90 and 80 per cent P. F. the above figures should be multiplied by 1.1 and 1.25 respectively.

Full-Load Current*

Three-Phase A.C. Motors

	Induction Type Squirrel-Cage and Wound Rotor Amperes					Synchronous Type †Unity Power Factor Amperes			
HP	110V	220V	440V	550V	2300V	220V	440V	550V	2300V
½	4	2	1	.8					
¾	5.6	2.8	1.4	1.1					
1	7	3.5	1.8	1.4					
1½	10	5	2.5	2.0					
2	13	6.5	3.3	2.6					
3		9	4.5	4					
5		15	7.5	6					
7½		22	11	9					
10		27	14	11					
15		40	20	16					
20		52	26	21					
25		64	32	26	7	54	27	22	5.4
30		78	39	31	8.5	65	33	26	6.5
40		104	52	41	10.5	86	43	35	8
50		125	63	50	13	108	54	44	10
60		150	75	60	16	128	64	51	12
75		185	93	74	19	161	81	65	15
100		246	123	98	25	211	106	85	20
125		310	155	124	31	264	132	106	25
150		360	180	144	37		158	127	30
200		480	240	192	48		210	168	40

For full-load currents of 208 and 200-volt motors, increase the corresponding 220-volt motor full-load current by 6 and 10 per cent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

†For 90 and 80 per cent P. F. the above figures should be multiplied by 1.1 and 1.25 respectively.

Number of Conductors in Conduit or Tubing
Rubber Covered, Types RF-2, RFH-2, R, RH, RHH, RHW, RW, RH-RW, RU, RUH, and RUW
Thermoplastic, Types TF, T and TW
One to Nine Conductors

Size AWG MCM	Number of Conductors in One Conduit or Tubing								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	*1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1½	1½	2	2½	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	5
300	1¼	2½	2½	3	3½	4	4	5	5
350	1¼	3	3	3½	3½	4	5	5	5
400	1½	3	3	3½	4	4	5	5	5
500	1½	3	3	3½	4	5	5	5	6
600	2	3½	3½	4	5	5	6	6	6
700	2	3½	3½	5	5	5	6	6	...
750	2	3½	3½	5	5	6	6	6	...
800	2	3½	4	5	5	6	6	...	...
900	2	4	4	5	6	6	6		...
1000	2	4	4	5	6	6	...	...	...
1250	2½	5	5	6	6	..	...	...	...
1500	3	5	5	6	...	...	...	...	...
1750	3	5	6	6	...	...	...	...	...
2000	3	6	6	...	...	...	...	..	...

*Where a service run of conduit or electrical metallic tubing does not exceed 50 feet in length and does not contain more than the equivalent of two quarter bends from end to end two No 4 insulated and one No. 4 bare conductors may be installed in 1-inch conduit or tubing.

Useful Information

To find the circumference of a circle, multiply the diameter by 3.1416.

To find the diameter of a circle, multiply the circumference by .31831.

To find the area of a circle, multiply the square of the diameter by .7854.

The radius of a circle × 6.283185 = the circumference.

The square of the circumference of a circle × .07958 = the area.

Half the circumference of a circle × half its diameter = the area.

The circumference of a circle × .159155 = the radius.

The square root of the area of a circle × .56419 = the radius.

The square root of the area of a circle × 1.12838 = the diameter.

To find the diameter of a circle equal in area to a given square, multiply a side of the square by 1.12838.

To find the side of a square equal in area to a given circle, multiply the diameter by .8862.

To find the side of a square inscribed in a circle, multiply the diameter by .7071.

To find the side of a hexagon inscribed in a circle, multiply the diameter of the circle by .500.

To find the diameter of a circle inscribed in a hexagon, multiply a side of the hexagon by 1.7321.

To find the side of an equilateral triangle inscribed in a circle, multiply the diameter of the circle by .866.

To find the diameter of a circle inscribed in an equilateral triangle, multiply a side of the triangle by .57735.

To find the area of the surface of a ball (sphere), multiply the square of the diameter by 3.1416.

To find the volume of a ball (sphere), multiply the cube of the diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

To find the pressure in pounds per square inch at the base of a column of water, multiply the height of the column in feet by .433.

A gallon of water (U. S. Standard) weighs 8.336 pounds and contains 231 cubic inches. A cubic foot of water contains 7½ gallons, 1728 cubic inches, and weighs 62.425 pounds at a temperature of about 39° F.
These weights change slightly above and below this temperature.

Tables and Data

In accordance with the standard practice approved by the American Standards Association, the ratio 25.4 mm = 1 inch is used for converting millimeters to inches. This factor varies only two millionths of an inch from the more exact factor 25.40005 mm, a difference so small as to be negligible for industrial length measurements.

Metric Measures

The metric unit of length is the meter = 39.37 inches.
The metric unit of weight is the gram = 15.432 grains.

The following prefixes are used for sub-divisions and multiples: Milli = $\frac{1}{1000}$, Centi = $\frac{1}{100}$, Deci = $\frac{1}{10}$, Deca = 10, Hecto = 100, Kilo = 1000, Myria = 10,000.

Metric and English Equivalent Measures

MEASURES OF LENGTH

Metric		*English*
1 meter	=	39.37 inches, or 3.28083 feet, or 1.09361 yards
.3048 meter	=	1 foot
1 centimeter	=	.3937 inch
2.54 centimeters	=	1 inch
1 millimeter	=	.03937 inch, or nearly 1-25 inch
25.4 millimeters	=	1 inch
1 kilometer	=	1093.61 yards, or 0.62137 mile

MEASURES OF WEIGHT

Metric		*English*
1 gram	=	15.432 grains
.0648 gram	=	1 grain
28.35 grams	=	1 ounce avoirdupois
1 kilogram	=	2.2046 pounds
4536 kilogram	=	1 pound
1 metric ton 1000 kilograms	=	.9842 ton of 2240 pounds 19.68 cwt. 2201.6 pounds
1.016 metric tons 1016 kilograms	=	1 ton of 2240 pounds

MEASURES OF CAPACITY

Metric		*English*
1 liter (= 1 cubic decimeter)	=	61.023 cubic inches .03531 cubic foot .2642 gal. (American) 2.202 lbs. of water at 62° F.
28.317 liters	=	1 cubic foot
3.785 liters	=	1 gallon (American)
4.543 liters	=	1 gallon (Imperial)

Tables and Data

English Conversion Table

Length

Inches	×	.0833	=	feet
Inches	×	.02778	=	yards
Inches	×	.00001578	=	miles
Feet	×	.3333	=	yards
Feet	×	.0001894	=	miles
Yards	×	36.00	=	inches
Yards	×	3.00	=	feet
Yards	×	.0005681	=	miles
Miles	×	63360.00	=	inches
Miles	×	5280.00	=	feet
Miles	×	1760.00	=	yards
Circumference of circle	×	.3188	=	diameter
Diameter of circle	×	3.1416	=	circumference

Area

Square inches	×	.00694	=	square feet
Square inches	×	.0007716	=	square yards
Square feet	×	144.00	=	square inches
Square feet	×	.11111	=	square yards
Square yards	×	1296.00	=	square inches
Square yards	×	9.00	=	square feet
Dia. of circle squared	×	.7854	=	area
Dia. of sphere squared	×	3.1416	=	surface

Volume

Cubic inches	×	.0005787	=	cubic feet
Cubic inches	×	.00002143	=	cubic yards
Cubic inches	×	.004329	=	U. S. gallons
Cubic feet	×	1728.00	=	cubic inches
Cubic feet	×	.03704	=	cubic yards
Cubic feet	×	7.4805	=	U. S. gallons
Cubic yards	×	46656.00	=	cubic inches
Cubic yards	×	27.00	=	cubic feet
Dia. of sphere cubed	×	.5236	=	volume

Weight

Grains (avoirdupois)	×	.002286	=	ounces
Ounces (avoirdupois)	×	.0625	=	pounds
Ounces (avoirdupois)	×	.00003125	=	tons
Pounds (avoirdupois)	×	16.00	=	ounces
Pounds (avoirdupois)	×	.01	=	hundredweight
Pounds (avoirdupois)	×	.0005	=	tons
Tons (avoirdupois)	×	32000 00	=	ounces
Tons (avoirdupois)	×	2000.00	=	pounds

English Conversion Table

Energy

Horsepower	×	33000.	=	ft.-lbs. per min.
B. t. u.	×	778.26	=	ft.-lbs.
Ton of refrigeration	×	200.	=	B. t. u. per min.

Pressure

Lbs. per sq. in.	×	2.31	=	ft. of water (60°F.)
Ft .of water (60°F.)	×	.433	=	lbs. per sq. in.
Ins. of water (60°F.)	×	.0361	=	lbs. per sq. in.
Lbs. per sq. in.	×	27.70	=	ins. of water (60°F.)
Lbs. per sq. in.	×	2.041	=	ins. of Hg. (60°F.)
Ins. of Hg (60°F.)	×	.490	=	lbs. per sq. in.

Power

Horsepower	×	746.	=	watts
Watts	×	.001341	=	horsepower
Horsepower	×	42.4	=	B. t. u. per min.

Water Factors (at point of greatest density—39.2°F)

Miners inch (of water)	×	8.976	=	U. S .gals. per min.
Cubic inches (of water)	×	.57798	=	ounces
Cubic inches (of water)	×	.036124	=	pounds
Cubic inches (of water)	×	.004329	=	U. S. gallons
Cubic inches (of water)	×	.003607	=	English gallons
Cubic feet (of water)	×	62.425	=	pounds
Cubic feet (of water)	×	.03121	=	tons
Cubic feet (of water)	×	7.4805	=	U. S. gallons
Cubic feet (of water)	×	6.232	=	English gallons
Cubic foot of ice	×	57.2	=	pounds
Ounces (of water)	×	1.73	=	cubic inches
Pounds (of water)	×	26.68	=	cubic inches
Pounds (of water)	×	.01602	=	cubic feet
Pounds (of water)	×	.1198	=	U. S. gallons
Pounds (of water)	×	.0998	=	English gallons
Tons (of water)	×	32.04	=	cubic feet
Tons (of water)	×	239.6	=	U. S. gallons
Tons (of water)	×	199.6	=	English gallons
U. S. gallons	×	231.00	=	cubic inches
U. S. gallons	×	.13368	=	cubic feet
U. S. gallons	×	8.345	=	pounds
U. S. gallons	×	.8327	=	English gallons
U. S. gallons	×	3.785	=	liters
English gallons (Imperial)	×	277.41	=	cubic inches
English gallons (Imperial)	×	.1605	=	cubic feet
English gallons (Imperial)	×	10.02	=	pounds
English gallons (Imperial)	×	1.201	=	U. S. gallons
English gallons (Imperial)	×	4.546	=	liters

Metric Conversion Table

Length

Millimeters	×	.03937	= inches
Millimeters	÷	25.4	= inches
Centimeters	×	.3937	= inches
Centimeters	÷	2.54	= inches
Meters	×	39.37	= inches (Act. Cong.)
Meters	×	3.281	= feet
Meters	×	1.0936	= yards
Kilometers	×	.6214	= miles
Kilometers	÷	1.6093	= miles
Kilometers	×	3280.8	= feet

Area

Sq. Millimeters	×	.00155	= sq. in.
Sq. Millimeters	÷	645.2	= sq. in.
Sq. Centimeters	×	.155	= sq. in.
Sq. Centimeters	÷	6.452	= sq. in.
Sq. Meters	×	10.764	= sq. ft.
Sq. Kilometers	×	247.1	= acres
Hectares	×	2.471	= acres

Volume

Cu. Centimeters	÷	16.387	= cu. in.
Cu. Centimeters	÷	3.69	= fl. drs. (U.S.P.)
Cu. Centimeters	÷	29.57	= fl. oz. (U.S.P.)
Cu. Meters	×	35.314	= cu. ft.
Cu. Meters	×	1.308	= cu. yards
Cu. Meters	×	264.2	= gals. (231 cu. in.)
Litres	×	61.023	= cu. in. (Act. Cong.)
Litres	×	33.82	= fl. oz. (U.S.P.)
Litres	×	.2642	= gals. (231 cu. in.)
Litres	÷	3.785	= gals. (231 cu. in.)
Litres	÷	28.317	= cu. ft.
Hectolitres	×	3.531	= cu. ft.
Hectolitres	×	2.838	= bu. (2150.42 cu. in.)
Hectolitres	×	.1308	= cu. yds.
Hectolitres	×	26.42	= gals. (231 cu. in.)

Weight

Grams	×	15.432	= grains (Act. Cong.)
Grams	÷	981.	= dynes
Grams (water)	÷	29.57	= fl. oz.
Grams	÷	28.35	= oz. avoirdupois
Kilo-grams	×	2.2046	= lbs.

Metric Conversion Table (Cont.)

Weight

Kilo-grams	×	35.27	= oz. avoirdupois
Kilo-grams	×	.0011023	= tons (2000 lbs.)
Tonneau (Metric ton)	×	1.1023	= tons (2000 lbs.)
Tonneau (Metric ton)	×	2204.6	= lbs.

Unit Weight

Grams per cu. cent.	÷	27.68	= lbs. per cu. in.
Kilo per meter	×	.672	= lbs. per ft.
Kilo per cu. meter	×	.06243	= lbs. per cu. ft.
Kilo per Cheval	×	2.235	= lbs. per h. p.
Grams per liter	×	.06243	= lbs. per cu. ft.

Pressure

Kilo-grams per sq. cm.	×	14.223	= lbs. per sq. in.
Kilo-grams per sq. cm.	×	32 843	= ft. of water (60°F.)
Atmospheres (international)	×	14.696	= lbs. per sq. in

Energy

Joule	×	.7376	= ft. lbs.
Kilo-gram meters	×	7.233	= ft. lbs.

Power

Cheval vapeur	×	.9863	= h. p.
Kilo-watts	×	1.341	= h. p.
Watts	÷	746.	= h. p.
Watts	×	.7373	= ft. lbs. per sec

Miscellaneous

Kilogram calorie	×	3.968	= B. t. u.
Standard gravity (Sea level 45° lat.)	÷	980.665	= centimeters per sec. per sec.
Frigories/hr. (French)	+	3023.9	= Tons refrigeration

The following pages show temperatures on Fahrenheit and Centigrade thermometers.

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
—459.4	—273	—21.	—29.4	17.6	—8.	56.	13.3
—436.	—270.	—20.2	—29.	18.	—7.8	57.	13.9
—418.	—260.	—20.	—28.9	19.	—7.2	57.2	14.
—400.	—210.	—19.	—28.3	19.4	—7.	58.	14.4
—382.	—230.	—18.4	—28.	20.	—6.7	59.	15.
—364.	—220.	—18.	—27.8	21.	—6.1	60.	15.6
—346.	—210.	—17.	—27.2	21.2	—6.	60.8	16.
—328.	—200.	—16.6	—27.	22.	—5.6	61.	16.1
—310.	—190.	—16.	—26.7	23.	—5.	62.	16.7
—292.	—180.	—15.	—26.1	24.	—4.4	62.6	17.
—274.	—170.	—14.8	—26.	24.8	—4.	63.	17.2
—256.	—160.	—14.	—25.6	25.	—3.9	64.	17.8
—238.	—150.	—13.	—25.	26.	—3.3	64.4	18.
—220.	—140	—12.	—24.4	26.6	—3.	65.	18.3
—202.	—130.	—11.2	—24.	27.	—2.8	66.	18.9
—184.	—120.	—11.	—23.9	28.	—2.2	66.2	19.
—166.	—110.	—10.	—23.3	28.4	—2.	67.	19.4
—148.	—100.	— 9.4	—23.	29.	—1.7	68.	20.
—139.	— 95.	— 9.	—22.8	30.	—1.1	69.	20.6
—130.	— 90.	— 8.	—22.2	30.2	—1.	69.8	21.
—121.	— 85.	— 7.6	—22.	31.	—0.6	70.	21.1
—112.	— 80.	— 7.	—21.7	32.	0.	71.	21.7
—103.	— 75	— 6.	—21.1	33.	+0.6	71.6	22.
— 94.	— 70.	— 5.8	—21.	33.8	1.	72.	22.2
— 85.	— 65.	— 5.	—20.6	34.	1.1	73.	22.8
— 76.	— 60.	— 4.	—20.	35.	1.7	73.4	23.
— 67.	— 55.	— 3.	—19.4	35.6	2.	74.	23.3
— 58.	— 50.	— 2.2	—19.	36.	2.2	75.	23.9
— 49.	— 45.	— 2.	—18.9	37.	2.8	75.2	24.
— 40.	— 40.	— 1.	—18.3	37.4	3.	76.	24.4
— 39.	— 39.4	— 0.4	—18.	38.	3.3	77.	25.
— 38.2	— 39.	0.	—17.8	39.	3.9	78.	25.6
— 38.	— 38.9	+ 1.	—17.2	39.2	4.	78.8	26.
— 37.	— 38.3	1.4	—17.	40.	4.4	79.	26.1
— 36.4	— 38.	2.	—16.7	41.	5.	80.	26.7
— 36.	— 37.8	3.	—16.1	42.	5.6	80.6	27.
— 35.	— 37.2	3.2	—16.	42.8	6.	81.	27.2
— 34.6	— 37.	4.	—15.6	43.	6.1	82.	27.8
— 34.	— 36.7	5.	—15.	44.	6.7	82.4	28.
— 33.	— 36.1	6.	—14.4	44.6	7.	83.	28.3
— 32.8	— 36.	6.8	—14.	45.	7.2	84.	28.9
— 32.	— 35.6	7.	—13.9	46.	7.8	84.2	29.
— 31.	— 35.	8.	—13.3	46.4	8.	85.	29.4
— 30.	— 34 4	8.6	—13.	47.	8.3	86.	30.
— 29.2	— 34.	9.	—12.8	48.	8.9	87.	30.6
— 29.	— 33.9	10.	—12.2	48.2	9.	87.8	31.
— 28.	— 33.3	10.4	—12.	49.	9.4	88.	31.1
— 27.4	— 33.	11.	—11.7	50.	10.	89.	31.7
— 27.	— 32.8	12.	—11.1	51.	10.6	89.6	32.
— 26.	— 32 2	12.2	—11.	51.8	11.	90.	32.2
— 25.6	— 32.	13.	—10.6	52.	11.1	91.	32.8
— 25.	— 31.7	14.	—10.	53.	11.7	91.4	33.
— 24.	— 31.1	15.	— 9.4	53.6	12.	92.	33.3
— 23.8	— 31.	15.8	— 9.	54.	12.2	93.	33.9
— 23.	— 30.6	16.	— 8.9	55.	12.8	93.2	34.
— 22.	— 30.	17.	— 8.3	55.4	13.	94.	34.4

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs	Centigrade Degs	Fahrenheit Degs	Centigrade Degs	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
95.	35.	134.	56.7	172.4	78.	211.	99.4
96.	35.6	134.6	57.	173.	78.3	212.	100.
96.8	36.	135.	57.2	174.	78.9	213.	100.6
97.	36.1	136.	57.8	174.2	79.	213.8	101.
98.	36.7	136.4	58	175.	79.4	214.	101.1
98.6	37.	137.	58.3	176.	80.	215.	101.7
99.	37.2	138	58.9	177.	80.6	215.6	102.
100.	37.8	138.2	59.	177.8	81.	216.	102.2
100.4	38.	139.	59.4	178.	81.1	217.	102.8
101.	38.3	140.	60.	179.	81.7	217.4	103.
102.	38.9	141.	60.6	179.6	82.	218.	103.3
102.2	39.	141.8	61.	180.	82.2	219.	103.9
103.	39.4	142.	61.1	181.	82.8	219.2	104.
104.	40.	143.	61.7	181.4	83.	220.	104.4
105	40.6	143.6	62.	182.	83.3	221.	105.
105.8	41.	144.	62.2	183.	83.9	222.	105.6
106.	41.1	145	62.8	183.2	84.	222.8	106.
107.	41.7	145.4	63.	184.	84.4	223.	106.1
107.6	42.	146.	63.3	185.	85.	224.	106.7
108.	42.2	147.	63.9	186.	85.6	224.6	107.
109.	42.8	147.2	64.	186.8	86.	225.	107.2
109.4	43.	148.	64.4	187.	86.1	226.	107.8
110.	43.3	149.	65.	188.	86.7	226.4	108.
111.	43.9	150.	65.6	188.6	87.	227.	108.3
111.2	44.	150.8	66.	189.	87.2	228.	108.9
112.	44.4	151.	66.1	190.	87.8	228.2	109.
113.	45.	152.	66.7	190.4	88	229.	109.4
114.	45.6	152.6	67.	191.	88.3	230.	110.
114.8	46.	153.	67.2	192.	88.9	231.	110.6
115.	46.1	154.	67.8	192.2	89.	231.8	111.
116.	46.7	154.4	68.	193.	89.4	232.	111.1
116.6	47.	155.	68.3	194.	90.	233.	111.7
117.	47.2	156.	68.9	195.	90.6	233.6	112.
118.	47.8	156.2	69.	195.8	91.	234.	112.3
118.4	48.	157.	69.4	196.	91.1	235.	112.8
119.	48.3	158.	70.	197.	91.7	235.4	113.
120.	48.9	159.	70.6	197.6	92.	236.	113.3
120.2	49.	159.8	71.	198.	92.2	237.	113.9
121.	49.4	160.	71.1	199.	92.8	237.2	114.
122.	50.	161.	71.7	199.4	93.	238.	114.4
123.	50.6	161.6	72.	200.	93.3	239.	115.
123.8	51.	162.	72.2	201.	93.9	240.	115.6
124.	51.1	163.	72.8	201.2	94.	240.8	116.
125.	51.7	163.4	73.	202.	94.4	241.	116.1
125.6	52.	164.	73.3	203.	95.	242.	116.7
126.	52.2	165.	73.9	204.	95.6	242.6	117.
127.	52.8	165.2	74.	204.8	96.	243.	117.2
127.4	53.	166.	74.4	205.	96.1	244.	117.8
128.	53.3	167.	75.	206.	96.7	244.4	118.
129.	53.9	168.	75.6	206.6	97.	245.	118.3
129.2	54.	168.8	76.	207.	97.2	246.	118.9
130.	54.4	169.	76.1	208.	97.8	246.2	119.
131.	55.	170.	76.7	208.4	98.	247.	119.4
132.	55.6	170.6	77.	209.	98.3	248.	120.
132.8	56.	171.	77.2	210.	98.9	249.	120.6
133.	56.1	172.	77.8	210.2	99.	249.8	121.